Benefit Estimates of Synthetic Vision Technology

NS002S1

July 2000

Robert V. Hemm, Jr.

Benefit Estimates of Synthetic Vision Technology

NS002S1/JULY 2000

Executive Summary

NASA is pursuing Synthetic Vision System (SVS) technology to improve aviation safety. Besides safety benefits, SVS technology has potential economic benefits that will ultimately be vital for industry acceptance and implementation. NASA program managers want to ensure that the requirements being developed for the SVS demonstrations include the capabilities that have significant economic impact. LMI was tasked to estimate the economic impact of the SVS capabilities to provide input to the NASA SVS Concept of Operations (CONOPS) document.

Synthetic vision implies the presentation to the pilot of a computer-generated view of the external environment. The SVS presentation is completely artificial. It is typically based on static geographical and cultural data supplemented by dynamic traffic information. Current experimental implementations of SVS use Global Positioning Satellite (GPS) position data to dynamically register the data base information to the aircraft's position and attitude. Supplemental sensors may be used to confirm the GPS position data and provide additional data (e.g., other aircraft, weather events, ground equipment). Synthetic vision systems can use both head-up and head-down displays, but the current concept focuses on a head-down display. Displays can include an artificial out-of-the-window view (in all directions) or any number of symbolic and map presentations.

Synthetic vision systems should provide several improvements in airport terminal area operations. Among these are reduced arrival and departure minimums, use of additional multi-runway configurations, independent operations on closely spaced parallel runways, and reduced arrival spacing. Using modified versions of airport capacity and delay models previously developed to analyze other NASA technologies, we estimated how much these improvements would reduce arrival and departure delays. The analysis results indicate that SVS technologies should provide large economic benefits, but that different capabilities are important at different airports.

The results indicate that the ability to conduct circling and converging approaches will provide major benefits at two key airports (Chicago, Newark). Reduced arri-

val separations are essential at two other key airports (Atlanta, Los Angeles). The remainder of the capabilities provide significant, but lesser, benefits. The ability to conduct low visibility ground operations at normal visual tempo is an essential enabling capability for all benefits. The CONOPS should include requirements that support these capabilities. We recommend the following demonstrations be included in SVS testing.

- Tests and simulations to demonstrate the ability to safely conduct converging and circling operations in IFR Cat IIIb conditions.
- Tests and simulations to demonstrate the ability for an aircrew to autonomously follow and hold position behind a leading aircraft in the traffic pattern and on final approach. Determine distance from the threshold of the last position adjustment.
- Tests and simulations to demonstrate, as a minimum, the ability to conduct arrival and departure operations under conditions of 0-foot ceiling and 300-foot runway visual range (RVR) with a goal of demonstrating operations at 0-foot RVR.
- Tests and simulations to demonstrate the ability to conduct ground operations at visual flight rule tempos with visibility as low as 300 feet.
- Tests and analysis to determine the minimum operational hardware requirements for each of the capabilities above. Specifically,
  - whether a head-up display is technically required for each capability.
  - the minimum hardware suite necessary to provide FAA-required system performance and reliability.

Chapter 1
Overview and Summary Results

This chapter describes the synthetic vision system (SVS) technologies, the methods used to estimate their potential benefits, and a summary of the results. Chapter 2 discusses the results and their implications for the SVS development program. Chapter 3 documents individual airport results. Appendix A addresses the ability of SVS to increase airport capacity through reduced inter-arrival separations.

Background

Synthetic vision implies the presentation to the pilot of a computer-generated view of the external environment. The SVS presentation is completely artificial. It is typically based on static geographical and cultural data supplemented by dynamic traffic information. Current experimental implementations of SVS use Global Positioning Satellite (GPS) position data to dynamically register the database information to the aircraft's position and attitude. Supplemental sensors may be used to confirm the GPS position data and provide additional data (e.g., other aircraft, weather events, ground equipment). Synthetic vision systems can use both head-up and head-down displays, but the current concept focuses on a head-down display. Displays can include an artificial out-of-the-window view (in all directions) or any number of symbolic and map presentations.

In a broad sense, synthetic vision includes all artificial information that represents the real world. For example, the wire frame runway edge symbols generated from Instrument Landing System data that are featured on some current guidance systems can be considered synthetic vision. For this study, however, synthetic vision implies display of comprehensive geographic, cultural, and tactical data.

To avoid a common source of confusion, we note here the difference between "enhanced" vision (EVS) and "synthetic" vision (SVS). Enhanced vision refers to the direct presentation to the aircrew of data from weather and darkness-penetrating sensors such as radar forward looking infrared (FLIR). The data presented is derived directly from the environment and not from a computer database. While EVS systems can use both head-down and head-up displays, in our analysis EVS includes a head-up display with sensor data registered to the real-world scene. EVS displays are limited to the field of regard of the sensor.

Technology Set Description

In our analysis we compare the benefits for five technologies to a 2005 technology baseline. The technologies are defined by their capabilities rather than by their hardware and software content. Our analysis thus provides information on the benefits of capabilities. Through multiple meetings with NASA government and support personnel, plus participation in a NASA-sponsored SVS workshop at Langley Research Center (LaRC), we have tried to ensure that the technology sets and modeling parameters include capabilities that are both comprehensive and feasible.

Hardware and software configurations corresponding to the technologies have been postulated, but significant uncertainties exist regarding minimum requirements for sensors, displays, etc. Detailed hardware and software definitions are not needed for our present task other than to ensure that modeled capabilities are feasible. The NASA technology programs will ultimately determine the minimum hardware and software necessary to provide the capabilities.

The five technology sets include a baseline (BL) system enhanced with a current generation head-up navigation and landing system (BLH), an EVS, and three versions of a synthetic vision system (SVS 1–3). The capabilities of the technologies are shown in Table 1-1.

Table 1-1. Technology Performance Assumptions

Technology set	Departure minimum (ft.)	Arrival minimums ceiling/visibility* (ft.)	Comments
BL	700	Airport approach plate minimums	· Cat II and Cat III operations on Cat II runways with current Cat III ceiling and visibility minimums
BLH	300	Airport approach plate minimums	· Cat II and Cat III operations on Cat II runways with current Cat III ceiling and visibility minimums
EVS	300	50/700 (on Cat I runways)	· Cat II and Cat III operations on Cat II runways with reduced minimums on Cat I runways
SV1	700	0/600 (no 300 ft taxi capability)	· Cat II and Cat III operations on all runways with reduced Cat III ceiling and visibility minimums. · Converging and circling operations in all Instrument Flight Rules

SV2	300	0/300	· Cat II and Cat III operations on all runways with reduced Cat III ceiling and visibility minimums · Converging and circling operations in all IFR · Reduced low visibility runway occupancy time

Table 1-1. Technology Performance Assumptions (Continued)

Technology set	Departure minimum	Arrival minimums ceiling/visibility*	Comments
SV3	300	0/300	· Cat II and Cat III operations on all runways with reduced Cat III ceiling and visibility minimums · Converging and circling operations in all IFR · Reduced separations · Reduced low visibility runway occupancy time · Independent IFR operations on parallel runways with spacing ≥ 2500 ft

* ceiling = Decision Height (DH) or Alert Height (AH) in feet
visibility = Runway Visual Range (RVR) in feet

The following paragraphs describe the benefits contained in Table 1-1.

Departure Minimums: Most major airports currently have FAA Surface Movement Guidance Control System (SMGCS) plans that allow departures with runway visual ranges (RVRs) as low as 700 feet. Today, aircraft equipped with head-up displays coupled to navigation guidance systems are authorized make 300-foot RVR departures. Reduced departure minimum is the sole benefit of BLH over the baseline, and is one of the benefits included in the EVS, SV2, and SV3 technologies.

Arrival Minimums:[1] Arrival minimums are determined both by approach and roll-out limits and taxi limits. Many aircraft today are equipped with autoland systems that can technically land and roll-out in 0/0 (ceiling/RVR) conditions; however, primarily because of taxi limitations,[2] most Cat IIIb runways are limited to 0/600 arrivals.[3] We assume for the baseline that all aircraft in 2005 will be capable of landing at the lowest available runway minimums. The EVS adds the capability of landing on Cat I runways when minimums are as low as 50/700. The SV1 technology allows landing on all runways under 0/600 conditions. Both SV2 and SV3 technologies include ROTO and T-NASA[4] technologies that allow reduced runway occupancy time and VFR tempo taxi operations and, consequently, arrival operations under 0/300 conditions.[5]

Converging and Circling Approaches: All three synthetic vision technology sets are assumed to be able to support converging and circling approaches at the lowest arrival minimums. This allows use of additional runways at four of the airports we modeled (Chicago, Newark, Dallas, and Minneapolis). The implication of this assumption is that the synthetic vision system will provide adequate information to allow safe IFR separation and missed approach maneuvers in curving and converging flight.

Reduced Separations: We assume the SV3 technology will include sufficient reliability, accuracy, and information to allow reduced aircraft separations. SVS could reduce separations either by enabling aircrews to fly "visual" approaches in radar conditions or by allowing the controller to take advantage of the aircrew's ability to maintain accurate separations (reducing uncertainties and possibly the effective common path). Reduced separation potential is discussed in Appendix A.

---

[1] We note here the definitions of several air traffic control terms that occur throughout the report: VFR = visual flight rules, IFR = instrument flight rules, VFR1 = VFR where visual approaches are authorized, VFR2 = VFR where radar control is still required, IFR1 = basic instrument conditions, a.k.a., Category I (Cat I) IFR, Cat II = Category II IFR, Cat III = Category III IFR. Arrival ceiling and visibility arrival minimums decrease as we proceed from VFR1 through IFR Cat III. There are three subcategories of Cat III: Cat IIIa, Cat IIIb, and Cat IIIc, which also represent decreasing minimums. Cat IIIc, which defines zero ceiling / zero visibility operations, is not now authorized at any airport. Occasionally we use VMC, visual meteorological conditions, and IMC, instrument meteorological conditions in place of VFR and IFR; they are identical in meaning.

[2] Some arrivals minimums may also be controlled by terrain.

[3] Currently, the only U.S. runways authorized for 300 ft. RVR arrivals are: Atlanta—9R, Denver—34, 35L, 35R, Memphis—36R (landing only), and Seattle—16R.

[4] Both ROTO (Roll-Out and Turn-Off) and T-NASA (Taxi-Navigation and Situation Awareness) are NASA Terminal Area Productivity (TAP) program technologies. The former reduces runway occupancy time in low visibility conditions and the latter allows normal speed ground operations in low visibility.

[5] 300-foot RVR is the current design point for the Runway Incursion Program (RIPS), which is the follow-on to ROTO and T-NASA. The system being developed is technically capable of 0/0 operations.

Reduced Runway Occupancy Time: The use of ROTO technology in SV2 and SV3 allows reductions in low visibility runway occupancy time (ROT). While accurate ROT data in low visibility conditions is sparse, it is generally agreed that ROTs are longer in low visibility primarily because of the difficulties in making accurate turns at the exits. Reduced friction is also an issue in ice and snow. In accordance with Reference 1, we add 20 percent to the dry runway ROT in Cat II and Cat III conditions. The 20 percent penalty is removed when ROTO technology is available.

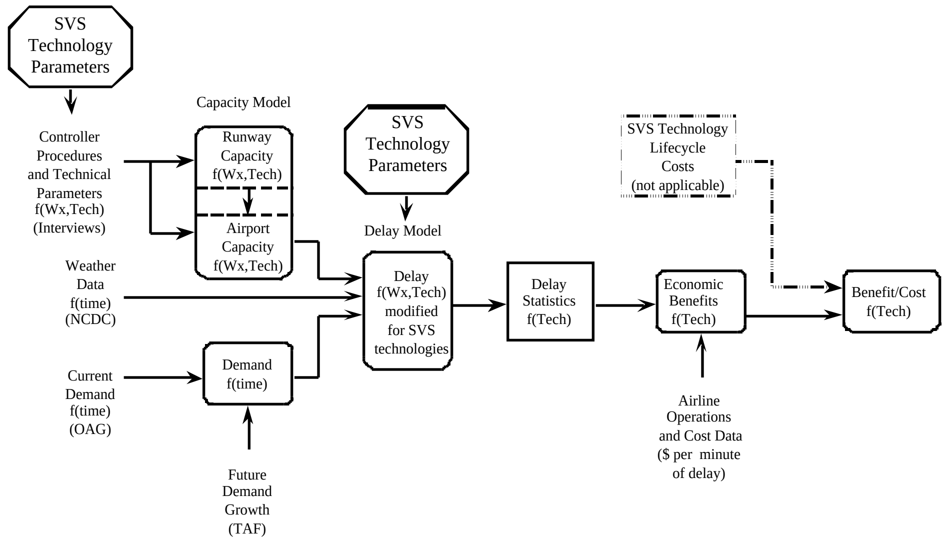
Independent Arrivals on Parallel with Centerline Spacing ≥ 2,500 feet: We assume the SV3 technology will include sufficient reliability, accuracy, and information to allow use of the procedures developed under the NASA Airborne Information for Lateral Spacing (AILS) program. Normally, runway centerline separation ≥4,300 feet is required for independent operations on parallel runways in radar-controlled conditions. Dependent (staggered) approaches are allowed between 2,500 and 4,300 feet. The equipment and procedures developed in the AILS program have demonstrated the ability to conduct independent approaches to parallel runways separated by as little as 2,500 feet in all weather conditions.

Benefit Analysis Approach

In this study, we use the analysis method previously used for benefit analysis of theTAP and AILS technologies. Using capacity and delay models for specific airports, we estimate the ability of the technologies to reduce delays.[6] Specifically, we estimate the reductions in delay for the 10 years from 2006 to 2015. We assume 2005 to be the year of technology deployment. Figure 1-1 outlines the analysis approach. For the current analysis all the delay models had to be modified to accommodate technology-dependent arrival and departure minimums. Some capacity models were also modified in cases where SVS allowed use of VFR configurations in IFR conditions. Costs for SVS technologies were not estimated in this task.

[6] We modeled 10 airports for this study: New York Kennedy (JFK), New York LaGuardia (LGA), Newark (EWR), Atlanta (ATL), Detroit (DFW), Chicago O’Hare (ORD), Dallas-Ft. Worth (DFW), Minneapolis-St. Paul (MSP), Seattle-Tacoma (SEA), and Los Angeles (LAX).

Figure 1–1. Overview of Analysis Method



Model Summary

While the details of the capacity and delay models are described in detail in Reference 2, a brief summary is useful for understanding and interpreting the results of the current analysis. We begin with the calculation of capacity for each airport runway configuration as a function of technology and meteorological condition. The result is a set of arrival and departure coordinates for each configuration/technolo-gy/ meteorological condition combination. The capacity curves generated from the coordinates define a trade-off frontier between arrivals and departures.[7] For each technology, one curve is generated for each meteorological condition (typically four) for each runway configuration (ranging from 2 for LAX to 23 for ORD).

Projected hourly demand is derived from Official Airline Guide (OAG) data and the FAA Terminal Area Forecast (TAF). In some cases, the demand is modified based on controller input or tower count data to account for additional general aviation. The base year demand derived from the OAG is inflated by factors derived from the TAF to generate hourly demands for future years. Hourly demand at airports typically varies by season and day of the week. Whenever appropriate, we include separate hourly demand sets for Saturdays, Sundays, and weekdays, plus summer and winter (i.e., six sets).

[7] The capacity curves are often called *Pareto* curves after the Italian scientist and economist Vilfredo Pareto (1848–1923). A *Pareto Optimality* is a situation where one individual could not be made better off without someone else being made worse off .(i.e., a zero-sum trade-off).

Weather data are taken from hourly weather service reports obtained from the U.S. Weather Service National Climatic Data Center for the airport. Ceiling, visibility, wind direction, and wind speed are the data used in the model. Precipitation data may also be used to identify wet and dry runway conditions.

With the capacity curves, hourly demand, and hourly weather data in hand, we turn to the task of estimating delay. The delay model is run once for each technology case and demand year. The delay model emulates the Traffic Management Unit's decision processes on an hour-by-hour basis. Beginning with the first hour the airport is open, the model examines the ceiling and visibility to determine the airport meteorological operating condition. Next, the model uses the wind speed and direction data to determine which runway configurations are legal. The model then looks to the arrival and departure demand for the hour, including any residual demand remaining from previous hours. The demand data are used to select the operating points on the capacity curves. The arrival and departure capacities of all legal configurations are examined and the highest capacity configuration is selected to determine the airport's capacity for the hour. The model may contain airport-specific restrictions to select preferred configurations or prevent unrealistic flip-flopping among configurations. The demand and capacity data are sent to a queuing routine to determine the delay for the current hour and the residual demand for the next hour.[8] The model then steps to the next hour and continues, hour-by-hour, day-by-day, and year-by-year until the weather data is exhausted. The arrival and departure delays are accumulated and averaged to provide average annual minutes of delay as a function of technology and demand year. From 19 to 35 years of hourly weather data are examined in each model run to produce reliable averages.

The benefit of the technology is based on the value of the minutes of delay avoided compared to the delay for the baseline. We calculated the delays for each of the years from 2005 through 2015. The savings for the 10 years, 2006 through 2015, are used to determine 10-year savings for the technology.

Two values of cost per minute of delay are used. The lower of the two includes only variable operating cost minus fuel and plus flight attendant costs (VOC-F+FA). The higher of the two is direct operating cost, which includes both capital depreciation and fuel plus flight attendant costs (DOC+FA). The DOC and VOC define upper and lower bounds on the cost of delay. For this study, we use the 1998 VOC-F+FA and DOC+FA values reported in the NASA Aviation Systems Analysis Capability (ASAC) report titled *Cost and Operational Data - Equipment Level*. The values from ASAC are \$44.71/minute for DOC+FA and \$27.15/minute

[8] We model an M/M/1 queue, that is a queue with a Poisson arrival rate, a Poisson service time, and a single server. The significance of this is that even when average capacity is above average demand, some delay will usually occur because arrivals and departures do not occur uniformly, nor do they take the same amount of time to handle.

for VOC-F+FA in 1998 dollars. Using a 2.2 percent inflation factor from the 2000 President's Economic Report,[9] we produce a DOC+FA value of $45.69 and a VOC-F-FA value of $27.75 in 1999 dollars. The average of the DOC+FA and VOC-F+FA costs is used for the summary savings table in this chapter while the upper and lower bounds are retained in the savings tables contained in the individual airport discussions. We also calculate discounted (a.k.a. Present Value) savings using a 1999 base and 7 percent discount factor, and inflated (a.k.a. Then-Year or Budget) savings using a 2.6 percent inflation rate.

Summary Results

Table 2 contains the average savings for the five technologies at the 10 airports. The savings are averaged two ways. First they are calculated using the average of the DOC+FA and VOC-F-FA values discussed above. This average roughly corresponds to half the delays being ground holds and half being airborne. The second average is over the 10 years from 2006 through 2015.

Table 1-2. Average Savings by Airport—Combined Arrival and Departure

Average Annual Minutes Saved (in millions)

Technology	Total	DFW	ORD	LAX	ATL	DTW	MSP	EWR	SEA	LGA	JFK
BLH	4.7	0.38	0.42	0.70	1.02	0.254	0.0741	0.15	1.40	0.20	0.16
EVS	5.9	0.38	0.55	0.70	1.04	0.31	0.42	0.15	1.54	0.44	0.33
SV1	12.8	0.82	6.21	0.20	0.03	0.09	0.71	3.94	0.32	0.38	0.15
SV2	20.6	1.64	7.22	1.60	1.40	0.59	0.92	4.07	1.94	0.59	0.57
SV3	45.2	4.76	8.99	8.58	9.58	1.36	1.65	4.48	2.52	2.11	1.18

Average Annual 1999 Constant Dollar Savings (in millions)

Technology	Total	DFW	ORD	LAX	ATL	DTW	MSP	EWR	SEA	LGA	JFK
BLH	174	14.0	15.4	25.6	37.3	9.3	2.72	5.6	51.4	7.2	5.8
EVS	215	14.1	20.3	25.6	38.2	11.3	15.3	5.6	56.5	16.0	11.9
SV1	472	30.2	228.0	7.3	1.0	3.2	26.1	144.6	11.8	14.0	5.6
SV2	755	60.4	265.2	58.8	51.5	21.7	33.9	149.6	71.2	21.6	20.9
SV3	1660	174.9	330.1	315.2	352.0	49.8	60.4	164.6	92.5	77.3	43.5

Average Annual 1999 Present Value Dollar Savings (in millions)

Technology	Total	DFW	ORD	LAX	ATL	DTW	MSP	EWR	SEA	LGA	JFK
BLH	81	6.5	7.1	12.0	17.4	4.2	1.246	2.6	23.5	3.4	2.7
EVS	99	6.5	9.5	12.0	17.9	5.1	7.0	2.6	25.8	7.5	5.5
SV1	217	13.6	104.8	3.4	0.5	1.4	11.6	67.7	5.2	6.5	2.6
SV2	348	27.5	121.9	27.5	24.1	9.8	15.1	70.0	32.3	10.1	9.7
SV3	765	78.6	151.1	147.5	164.7	21.8	26.7	77.0	41.4	35.9	20.0

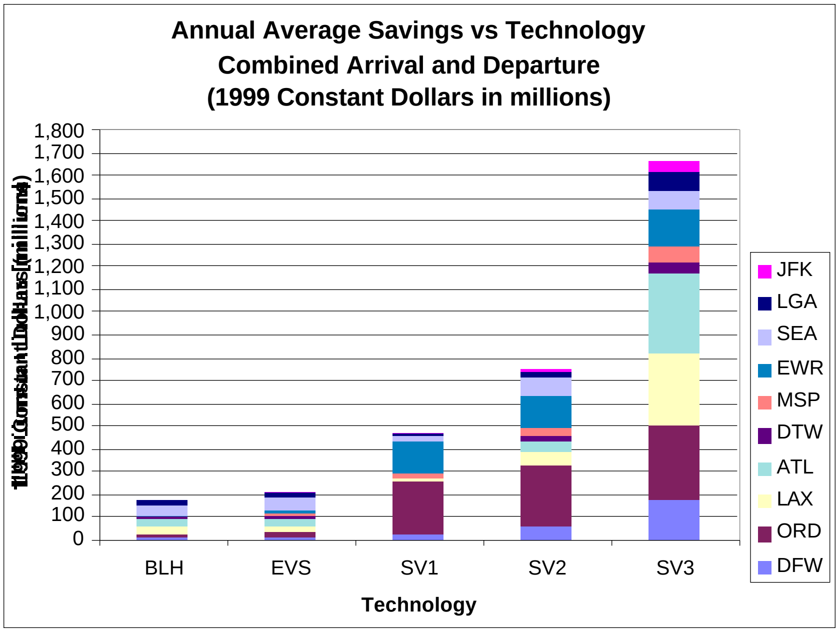
Average Annual Then Year Dollar Savings (in millions)

Technology	Total	DFW	ORD	LAX	ATL	DTW	MSP	EWR	SEA	LGA	JFK
BLH	236	19.0	20.9	34.5	50.2	12.7	3.695	7.5	70.0	9.7	7.9
EVS	291	19.1	27.4	34.5	51.4	15.5	20.9	7.5	76.8	21.6	16.2
SV1	639	41.2	309.2	9.9	1.3	4.3	35.9	194.8	16.2	18.9	7.6
SV2	1022	82.1	359.6	79.2	69.4	29.6	46.5	201.5	97.1	29.1	28.2
SV3	2250	239.0	448.4	424.6	474.1	68.7	83.3	221.7	126.7	104.5	59.0

Figure 1-2 shows the constant dollar results contained in Table 2.

[9] Table B-61–*Changes in special consumer price indexes, 1960-99*; All items (CPI-U), Year-to-year value

Figure 1–2. Average Annual Constant Dollar Savings—Combined Arrival and Departure



Chapter 2

Review of Results and CONOPS Recommendations

In this chapter we review the results of the analysis and implications for the SVS CONOPS.

REVIEW OF RESULTS

As discussed in Chapter 1, the benefits from SVS and related technologies can be included in the following categories that are here listed in the order of increasing effect:

- reduced ROT in low visibility,
- reduced departure minimums,
- reduced arrival minimums,
- converging and circling arrivals: use of dual and triple runway configurations in IFR conditions,
- reduced interarrival separations, and
- independent operations on closely-spaced parallel runways.

In addition to these, the ability of SVS to support VFR-tempo low visibility ground operations is vital to realizing the other benefits.

Reduced Runway Occupancy Time

ROTs are estimated to increase 20 percent with low visibility, wet conditions. The NASA ROTO technologies that are included with SV2 and SV3 are assumed to eliminate the 20 percent penalty. With SV2, ROT reductions will have no impact in low visibility conditions because arrival aircraft separations are determined by miles-in-trail (MIT) requirements. With SV3, the MIT separations are reduced and the ROT reductions provide some benefit. Delay model results for SV3, with and without the ROT reduction, indicate that ROT reduction has a relatively small effect on the benefits from reduced miles-in-trail separations.

Reduced Departure Minimums

Head-up guidance systems, enhanced vision systems, and SVS all will allow reduction of the 700-foot minimum departure visibility. Aircraft with head-up guidance systems are already authorized to depart with 300-foot visibility. The model results indicate that the potential benefit from the reduced departure minimum ranges from $3 million per year at Minneapolis to $51 million per year at Seattle.

Reduced Arrival Minimums

The results for the 10 airports indicate that reducing arrival minimums for the current IFR runway configurations has only marginal impact on delay. This result was surprising, but really should have been expected. At the airports we modeled, significant resources have been committed to low visibility instrument landing capability. Current capabilities are designed to meet the majority of expected conditions. Of the 10 airports, 8 have Cat IIIb runways, including two with 300-foot RVR capability.

Converging and Circling Approaches

We predict large benefits at ORD and EWR, and significant benefits at MSP and DFW for the use, in IFR conditions, of high-capacity multiple-runway configurations that are now available only in VFR conditions. Use of these configurations requires the ability to safely fly converging or circling approaches in IFR. The benefits also require that the additional runways have IFR Cat III arrival minimums. All the SVS technologies are assumed to allow converging and circling approaches in IFR. SV1 supports approaches down to 600-foot RVR, while SV2 and SV3 extend down to 300-foot RVR.

Reduced Interarrival Separations

We predict significant benefits at all airports for the reductions in IFR aircraft separations included in SV3. The benefits are large for ATL and LAX, where runway capacity is congested, and there is no way to add capacity other than building new runways. Because both the causes and amounts of separation reductions are sources of discussion, we include an extended discussion of reduced separations in Appendix A.

Independent Arrivals on Closely Spaced Parallel Runways

The NASA AILS technology enables independent approaches to parallel runways with centerline spacing of at least 2,500 feet. We assume SV3 includes the AILS capability and thus allows independent operations on closely spaced parallel runways at DTW, MSP, SEA, and JFK. Because SV3 also includes reduced separations (RS), we ran cases with and without RS and AILS to determine technologies were responsible for SV3 benefits. The results are shown in Table 2-1. The first row shows that combined RS and AILS together reduce delays below SV2 levels by 14 percent to 19 percent. We see from the data in the second and third rows that the results for RS and AILS are not additive; the benefits of the sum is less then the sum of the individual benefits. Except for JFK, a significant fraction of the benefits can be had with either RS or AILS independently. At JFK, only RS provides a significant benefit.[10]

Table 2-1. Relative Benefits of Reduced Separations and Independent Arrivals on Closely Spaced Parallel Runways

	JFK	SEA	MSP	DTW
SV3 savings relative to SV2: AILS + RS	0.14	0.17	0.17	0.19
Fraction of SV3 savings due to AILS without RS	0.12	0.68	0.70	0.74
Fraction of SV3 savings due to RS without AILS	0.91	0.51	0.39	0.51

Low Visibility Taxi

The arrival capacity benefits of SVS technologies cannot be realized if the landing aircraft cannot taxi expeditiously in low visibility conditions. The T-NASA system is the enabling technology that allows VFR-tempo ground operations in IFR. T-NASA is essentially the ground operations analog to airborne SVS; the aircrew navigates using synthetic representations of the runways, taxiways, gates, and traffic. T-NASA technology is designed to allow VFR-tempo ground operations with visibility as low as 300 feet. SV1 is assumed not to have T-NASA and, therefore, is effectively limited to 600-foot visibility operations. SV2 and SV3 include full T-NASA capability.

HARDWARE CONSIDERATIONS

As discussed in Chapter 1, the technology levels in our analysis are based on capability and are not tied firmly to hardware. Specific hardware implementations were, in fact, hypothesized and discussed during the task. In the end, it was decided that we cannot tell, before to testing, the specific hardware necessary to provide the levels of capability analyzed, and that, at this time, it is more accurate to refer to capabilities rather than hardware. That being said, it is useful for test

[10] At JFK, AILS improves the capacity of the Parallel 4s and Parallel 22s configurations, but, because of ground operations limitations, their capacities are still less than that of the Parallel 31s configuration. Because the model searches for the highest capacity usable configuration, the Parallel 31s continue to dominate operations and AILS has minimal impact.

planning purposes (and for future cost benefit analyses) to consider the *potential* hardware implementations that correspond to the technology levels.

Table 2-2 contains a hypothetical list of hardware for each technology implementation.

Table 2-2. Hypothetical Equipment Requirements

Technology	Aircraft equipment	Ground equipment
Baseline	LAAS receiver EGPWS TCAS CDTI data radio LNAV VNAV VSAD Autoland-capable autopilot FMS	LAAS ground equipment CDTI data radio ASDE-3
BLH	Baseline + Head-up display (HUD)*	Baseline
EVS	Baseline + HUD* + Enhanced vision sensor	Baseline
SV1	Baseline + ADS-B Database Head-down display	Baseline
SV2	Baseline + ADS-B Database Head-down display HUD	Baseline
SV3	Baseline + ADS-B Database Head-down display HUD Supplemental Sensor?	Baseline + Low visibility taxi equipment AMASS multi-lateration or vehicle GPS low visibility emergency vehicle sensor

* The head-up display is assumed to include navigation information such as that found in the Flight Dynamics, Inc. Head-Up Guidance System™

LASS: Local Area Augmentation System (precision GPS)
EPGWS: Enhanced Ground Proximity Warning System
TCAS: Traffic Alert and Collision Avoidance System
CDTI: Cockpit Display of Traffic Information
LNAV: Lateral Navigation
VNAV: Vertical Navigation
VSAD: Vertical Situation Awareness Display
ADS-B: Automatic Dependent Surveillance – Broadcast
HUD: Head-Up Display
ASDE-3: Airport Surface Detection Equipment – 3 (surface radar)
AMASS: Airport Movement Area Safety System

CONOPS Implications

Based on the predicted benefits and our assumptions about hypothetical hardware, we can now address recommendations for the NASA SVS CONOPS document. The results indicate that the ability to conduct circling and converging approaches

will provide major benefits at two key airports (Chicago, Newark). Reduced arrival separations are essential at two other key airports (Atlanta, Los Angeles). The remainder of the capabilities provide significant, but lesser, benefits. The ability to conduct low visibility ground operations at normal visual tempo is an essential enabling capability for all benefits. The CONOPS should include requirements that support these capabilities. We recommend the following demonstrations be included in SVS testing.

- tests and simulations to demonstrate the ability to safely conduct converging and circling operations in IFR Cat IIIb conditions;
- tests and simulations to demonstrate the ability for an aircrew to autonomously follow and hold position behind a leading aircraft in the traffic pattern and on final approach. Determine distance from the threshold of the last position adjustment;
- tests and simulations to demonstrate, as a minimum, the ability to conduct arrival and departure operations under conditions of 0-foot ceiling and 300-foot RVR with a goal of demonstrating operations at 0-foot RVR;
- tests and simulations to demonstrate the ability to conduct ground operations at visual flight rule (VFR) tempos with visibility as low as 300 feet; and
- tests and analysis to determine the minimum operational hardware requirements for each of the capabilities above. Specifically,
  - whether a head-up display is technically required for each capability, and
  - the minimum hardware suite necessary to provide FAA required system performance and reliability.

Chapter 3
Individual Airport Results

OVERVIEW

This chapter addresses the analysis and results for each of the 10 airports.

General Modeling Assumptions

PRACTICAL LIMITATIONS ON ESTIMATED DEMAND

The delay models require hourly arrival and departure demand data for each airport. The basic demand data are derived from the *Official Airline Guide* schedule, supplemented with information from airport personnel. To produce demand schedules for future years, the basic data are multiplied by factors derived from the FAA *Terminal Area Forecast* (TAF).

We have found in the past, that, for certain airports, demands based on the TAF projections result in infeasible delays. Because of this, we examine the baseline technology VFR delays for each airport and hold demand constant at the point where the delays become marginally unreasonable. Figure 3-1 shows the VFR delays for the 10 airports as a function of time where demand is based on the TAF factors. The figure indicates that two airports, ATL and EWR, are currently very congested, and that two others, LAX and DFW, will become very congested before 2015. Anecdotal information from airline sources and common sense support the premise that a new hub will be developed if average VFR delays much exceed 10 minutes per flight. Our results indicate that ATL and EWR delays already exceed 10 minutes per flight and LAX and DFW will also before 2015.[11] In our estimates, when delays become excessive we freeze the demand level for the remainder of the years to 2015. The enlarged data markers in Figure 3-1 indicate the years where demands were frozen for the four airports. Table 3-1 summarizes the demand years used in our analysis.

[11] Our demand estimates are based on the basic ability of the airport, defined by its capacity, to process the demand. Delays based on schedules may be lower due to padding.

Figure 3–1. Projected VFR Arrival Delays

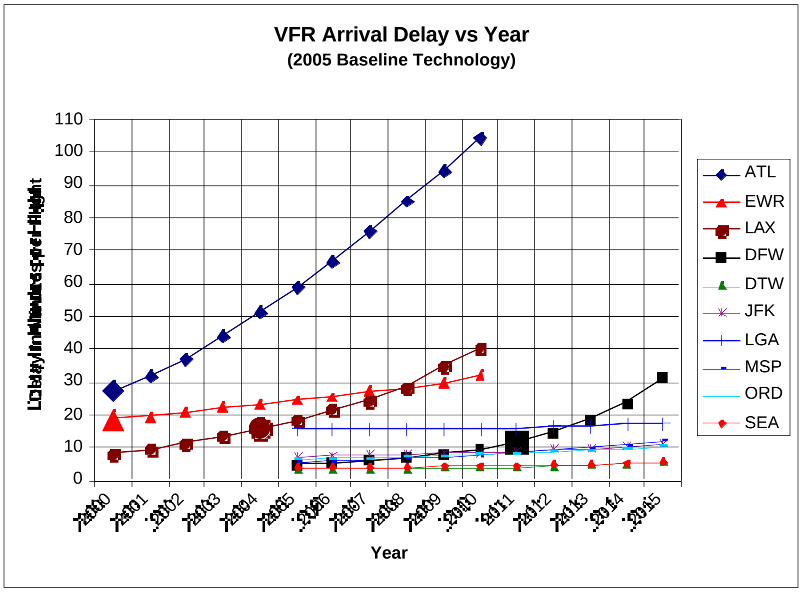


Table 3-1. Delay Analysis Demand Years

Airport	Airport code	Demand years
Atlanta	ATL	2000 only
Newark	EWR	2000 only
Los Angeles	LAX	2005–2004
Dallas-Fort Worth	DFW	2005–2011
Minneapolis-St. Paul	MSN	2005–2015
New York Kennedy	JFK	2005–2015
New York LaGuardia	LGA	2005–2015
Detroit	DTW	2005–2015
Chicago O’Hare	ORD	2005–2015
Seattle	SEA	2005–2015

AIRPORT RESULTS

Atlanta Hartsfield (ATL)

OPERATIONAL ISSUES

Atlanta is well-designed with two widely spaced pairs of parallel runways. There are some ground congestion problems and there are occasional departure delays caused by congestion in the crowded eastern enroute sectors. Most of the delay at Atlanta, however, is because the two arrival runways are running at or near capacity.

The primary flow direction at Atlanta is east. Runways 8L and 9R are equipped with Cat IIIb ILS. Atlanta runway 9R is one of the few runways in the United States capable of arrivals when visibility is only 300 feet. West flow arrival runways 26R and 27L are equipped with Cat I ILS. SVS technology allows Cat III operations in both directions.

Figure 3-2 shows the layout of ATL. Table 3-2 identifies the runway configurations used at ATL.

Figure 3–2. The William B. Hartsfield Atlanta International Airport, Atlanta, Georgia

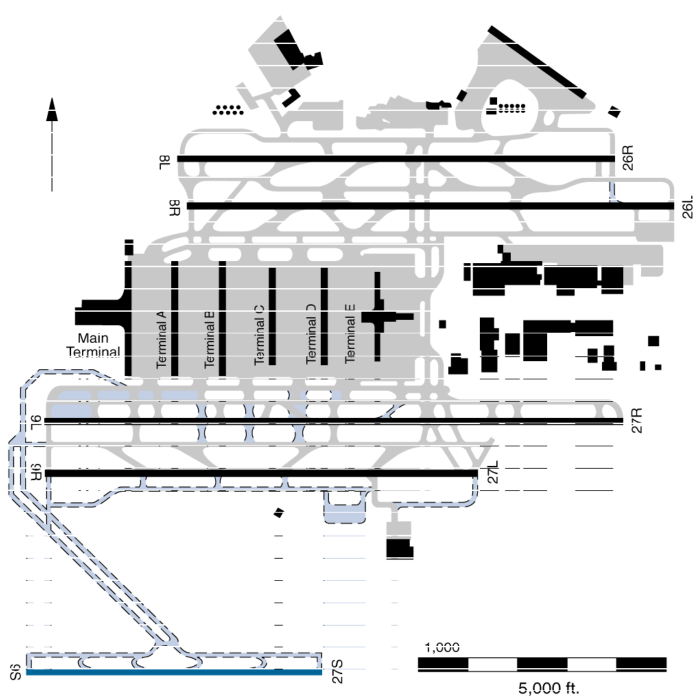


Table 3-2. Atlanta Configurations

Configuration	MC	Runway							
		8L	8R	9L	9R	27L	27R	26L	26R
East Flow: BL—SV3	VFR1—IFR Cat 2	A*	D	D	A*				
BL—SV1	Cat 3, 600 RVR	A*	D	D	A*				
BL—SV1	Cat 3, 300 RVR			D	A				
SV2—SV3	Cat 3, 300 RVR	A*	D	D	A*				
West Flow: BL - SV3	VFR1—IFR1					A*	D	D	A*
BL—EVS	Cat 2-3	closed							
SV1	Cat 2-3, 600 RVR					A*	D	D	A*
SV2—SV3	Cat 2-3, 300 RVR					A*	D	D	A*

* One of these runways will run departures during departure pushes

RESULTS

Figure 3-3 shows the annual delay for Atlanta as a function of technology. The delay curves are flat for Atlanta because the demand level was frozen at the year 2000 level as discussed in Chapter 1. Some improvement is seen for those technologies that reduce the take-off minimums from 700 to 300 feet. Little benefit is shown for reduction of arrival minimums because Atlanta already has one 300-foot visibility arrival runway, and the cases where East Flow is unavailable and West Flow is closed are rare. A dramatic improvement is shown for SV3 where reduced separations are added to reduced departure and arrival minimums.

Figure 3–3. Atlanta Combined Annual Arrival and Departure Delay versus Technology

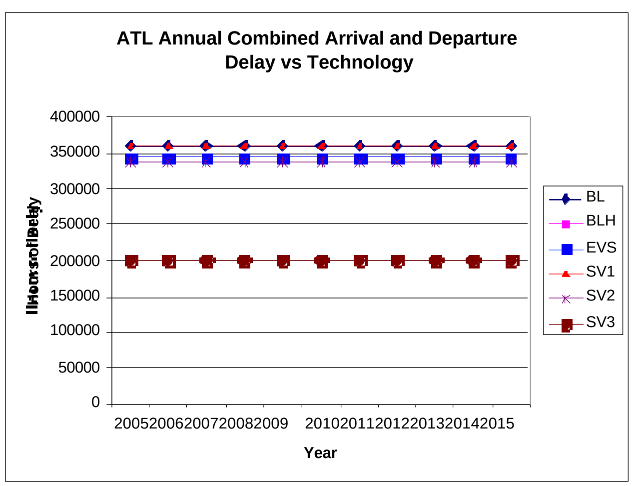


Table 3-3. 10-Year Savings for Atlanta

Technology	Minutes in millions	1997 constant $ in millions		Present value $ in millions		Then-year $ in millions	
		Lower bound	Upper bound	Lower bound	Upper bound	Lower bound	Upper bound
BLH	10.2	282	464	132	217	379	625
EVS	10.4	289	475	135	222	389	640
SV1	0.3	7	12	3	6	10	17
SV2	14.0	389	641	182	300	525	864
SV3	95.8	2,660	4,380	1,245	2,050	3,582	5,899

New York LaGuardia (LGA)

Operational Issues

LaGuardia has only two intersecting runways. The ability of arrivals to land and hold short at the intersection has a large effect on the capacities of the 4/13 and 31/4 configurations shown in Table 3-4. If the arrivals can hold short, then the two runways operate as an independent arrival and departure pair. If the arrivals do not hold short, then the runways operate as a single runway operating in an alternating arrival/departure mode. Historically, about 60 percent of the large aircraft and 40 percent of the heavy aircraft can hold short. When conditions are wet, no one can be expected to hold short. Based on discussions at the SVS workshop, we do not assume that SVS technologies will change current land and hold-short operations.

LaGuardia is currently equipped for only IFR Cat I operations. Enhanced vision and SVS technologies allow operations in Cat II & III conditions.

Figure 3–4. La Guardia Airport, New York, New York

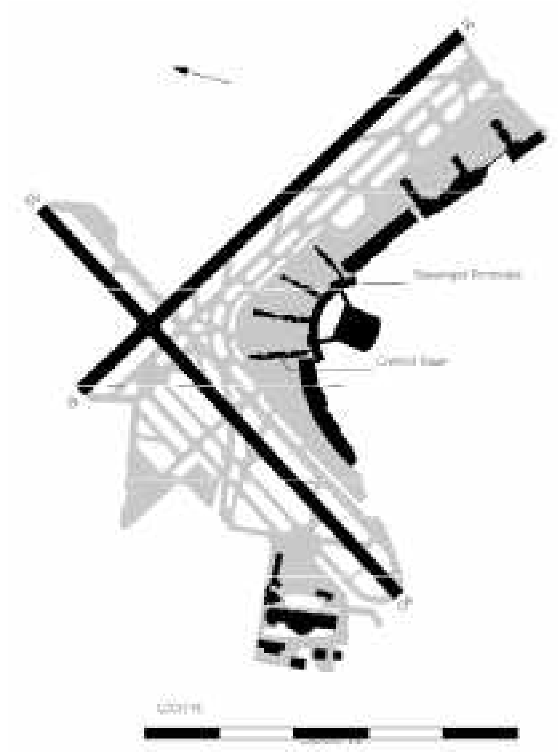


Table 3-4. LaGuardia Configurations

Configuration	MC	Runway			
		4	13	22	31
Single	MC 1-2	AD*	AD*	AD*	AD*
4/13 Dry	MC 3-4	A	D		
22/13	MC 1-2		D	A	
22/31	MC 3-4			A	D
31/4 Dry	MC 1-2	D			A
Wet	MC 3-4	AD**	AD**	AD**	AD**

* One runway only

** One pair of runways: arrive on one, depart on the other

RESULTS

Figure 3-3 and Table 3-5 show the results for LGA. The reductions in minimums provided by EVS and SVS technologies provide some savings, current congestion is sufficiently high that only the reduction in separations provided by SV3 results in really large savings.

Figure 3–5. LGA Combined Arrival and Departure Delay versus Technology

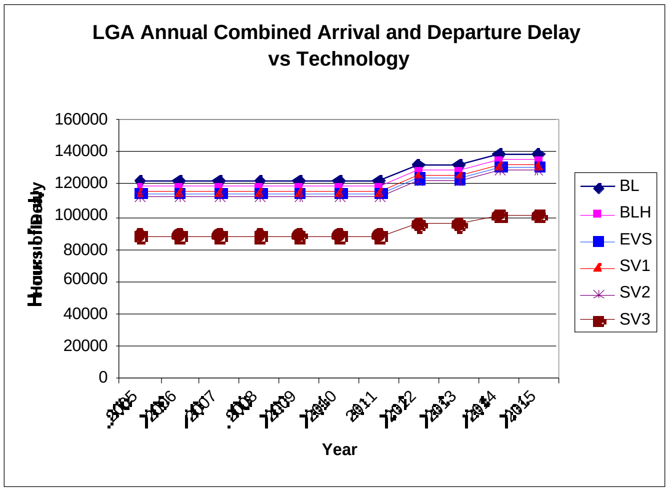


Table 3-5. 10-Year Savings for LGA

Technology	Minutes in millions	1997 Constant $ in millions		Present value $ in millions		Then-year $ in millions	
		Lower bound	**Upper bound**	**Lower bound**	**Upper bound**	**Lower bound**	**Upper bound**
BLH	2.0	55	90	25	42	74	121
EVS	4.4	121	199	56	93	163	268
SV1	3.8	106	174	49	81	143	235
SV2	5.9	163	269	76	125	220	362
SV3	21.1	584	962	271	447	790	1,301

New York John F. Kennedy International (JFK)

OPERATIONAL ISSUES

Kennedy Airport has a lot of concrete, moderate demand, and very congested airspace. Approach and departure routes conflict with those of LaGuardia and Newark. Airspace congestion results in common path lengths of 12 nautical miles for runways 22L and 22R, and 8 nautical miles for the rest. When using the parallel 31s, runway 31R is used for turboprop departures only. The model will assign some turboprops to the 31L departure mix if needed to balance the turboprop and jet departure rates.

Figure 3-6 shows the layout of JFK. Table 3-6 identifies the runway configurations used at JFK. Table 3-7 contains the JFK benefit estimates.

The impact of SVS technologies on JFK is through reduced minimums. The SV3 technology for JFK includes AILS technology, which enables independent arrivals on the parallel 22s and 4s during IFR.

Figure 3–6. John F. Kennedy International Airport, New York City

Table 3-6. New York Kennedy Configurations

Configuration	MC	Runway							
		4L	4R	22L	22R	31L	31R	13L	13R
Departure Only	IFR	D	D	D	D	D	D	D	D
13S Overflow 22	VFR			A				D	A/D
Depart 31L 22R	all			A	D	D			
Arrive 13R 22L	VFR			A	D				A
Arrive 4R 13L	VFR	D	A					A	
Depart 4L 31L	all	D	A			D			
Parallel 31	all						A/D	A/D	
Parallel 4	IFR	A/D dependent							
Parallel 4 AILS	IFR	A/D independent							
Parallel 22	IFR			A/D dependent					
Parallel 22 AILS	IFR			A/D independent					
Parallel 13	all							D	A
Parallel 31 Low Visibility	IFR					D	A/D		
Parallel 4 Low Visibility	IFR	D	A/D						
Parallel 22 Low Visibility	IFR			A/D	A				

RESULTS

Figure 3-7 and Table 3-7 show the savings for JFK. JFK shows good percentage savings for SVS technologies. The value of the benefits is modest, however, because the baseline delay is relatively low compared to LGA and other highly congested airports.

Figure 3–7. JFK Combined Arrival and Departure Delay versus Technology

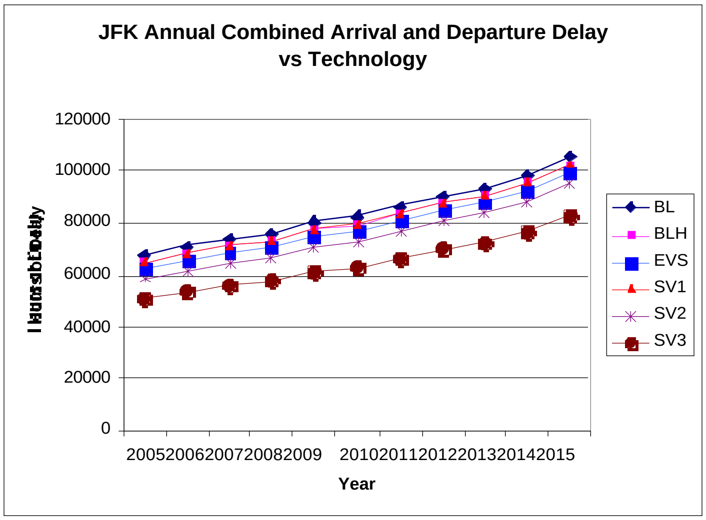


Table 3-7. JFK 10-Year Savings

Technology	Minutes in millions	1997 Constant $ in millions		Present Value $ in millions		Then Year $ in millions	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound
BLH	1.6	$44	$72	$20	$33	$59	$98
EVS	3.3	$90	$149	$42	$69	$122	$201
SVD	1.5	$43	$70	$20	$33	$58	$95
SVH	5.7	$158	$260	$73	$120	$213	$351
USV	11.8	$329	$541	$151	$249	$446	$734

Newark International (EWR)

OPERATIONAL ISSUES

The ability to use circling approaches to Runway 11 has a large effect on capacity at Newark. To accurately model that ability, we had to include a separate

IMC_CM circling minimum meteorological condition. In the Normal 22s or Normal 11s configurations, Runway 11/29 can be used for arrivals or departures but not for both at the same time.

We assume that SVS technology will allow use of circling approaches in IFR. This allows dual runway use at EWR in IFR and has a major effect on capacity.

Figure 3-8 shows the layout of EWR. Table 3-8 identifies the runway configurations used at EWR. Table 3-9 contains the EWR benefit estimates.

Figure 3–8. Newark International Airport, Newark, New Jersey

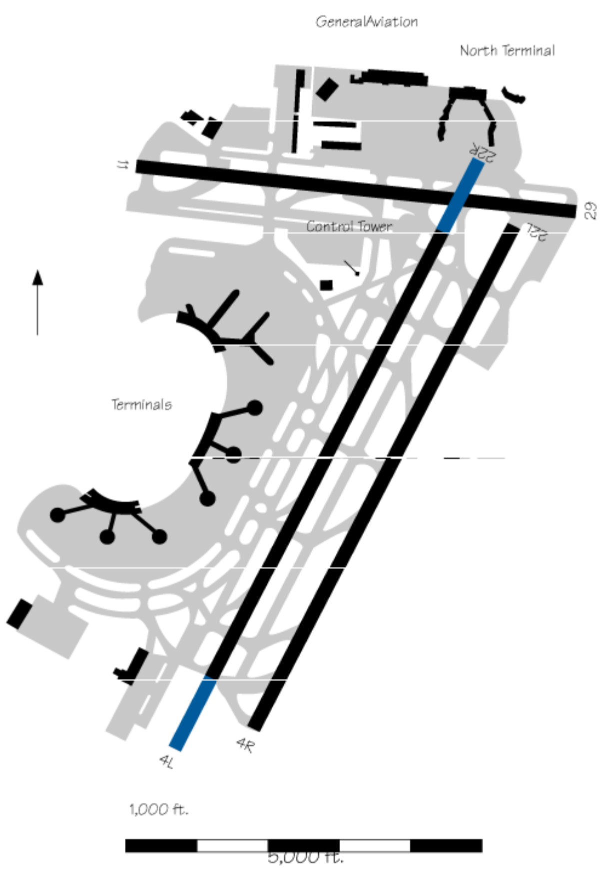


Table 3-8. Newark Configurations

Configuration	MC	Runway 4L	4R	22R	22L	29	11
Normal 22s	VFR/IFR circling or SVS			D	A	D*	A*
Normal 4s	VFR/IFR circling or SVS	D	A			D*	A*
22s only	IFR			D	A		
4s only	IFR	D	A				
4/11	VFR/IFR circling or SVS	D	A				A
4/29	VFR/IFR circling or SVS	D	A			D	
22/11	VFR/IFR circling or SVS			D	A		
22/29	VFR/IFR circling or SVS			D	A	D	

11/29 only	VFR/IFR circling or SVS					A/D	A/D

* Simultaneous operations not allowed.

RESULTS

Newark is one of the four airports where we had to limit the TAF-based demand increases because of congestion. Newark is already seriously congested and the demand was limited to the 2000 level.

Figure 3-9 and Table 3-9 show the results for EWR. The ability to use dual runways in IFR produces a tremendous benefit at Newark.

Figure 3–9. EWR Combined Arrival/Departure Delay

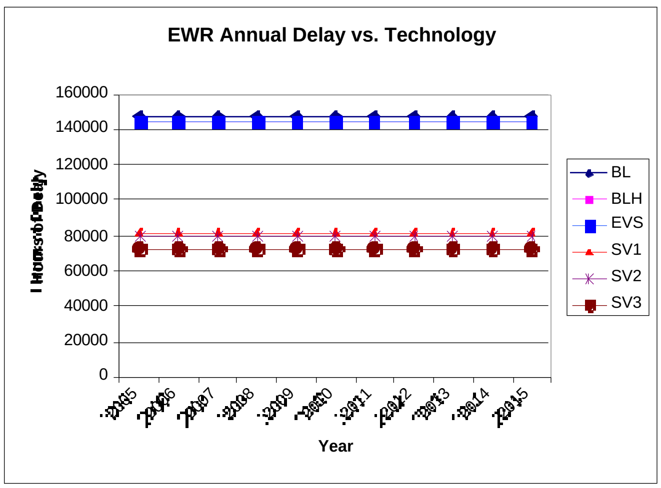


Table 3-9. 10-Year Savings for Newark

Technology	Minutes in millions	1997 Constant $ in millions		Present Value $ in millions		Then Year $ in millions	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound
BLH	1.5	$42	$70	$20	$33	$57	$94
EVS	1.5	$42	$70	$20	$33	$57	$94
SV1	39.4	$1,093	$1,800	$511	$842	$1,472	$2,424
SV2	40.7	$1,130	$1,861	$529	$871	$1,523	$2,507
SV3	44.8	$1,244	$2,048	$582	$958	$1,675	$2,759

Detroit Metropolitan Wayne County (DTW)

Operational Issues

Detroit has a high capacity runway configuration with widely spaced independent runways. Capacity can be limited by ground congestion, but a new terminal is planned that will improve the ground situation. The capacity on the 27 runways is artificially restricted by law for noise reasons. Our model includes the new parallel runway (4/22). Detroit's widely spaced parallel runways enable it to continue independent operations in IMC conditions.

Figure 3-10 shows the layout of DTW. Table 3-10 identifies the runway configurations used at DTW. Table 3-11 contains the DTW benefit estimates.

Figure 3–10. Detroit Metropolitan Wayne County Airport, Detroit, Michigan

Table 3-10. Detroit Wayne County Configurations With New Runway

Configuration	MC	Runways											
		22	21R	21C	21L	3R	3C	4	3L	27R	27L	9R	9L
22/21L/21C/21R	IFR w/o AILS	AD		D	A								

		dependent											
22/21L/21C/21R	VFR and IFR with AILS	AD independent		D	A								
4/3L/3C/3R	IFR w/o AILS					A	D	AD dependent					
4/3L/3C/3R	VFR and IFR with AILS					A	D	AD independent					
27L/27R	All									A	AD		
27L/27R/21R	All		D							A	A		

RESULTS

The results for DTW are shown in Figure 3-11 and Table 3-11. Savings for DTW start off rather modestly because of the high capacity of the airport, but increase in later years as demand grows.

Figure 3–11. DTW Combined Arrival and Departure Delay

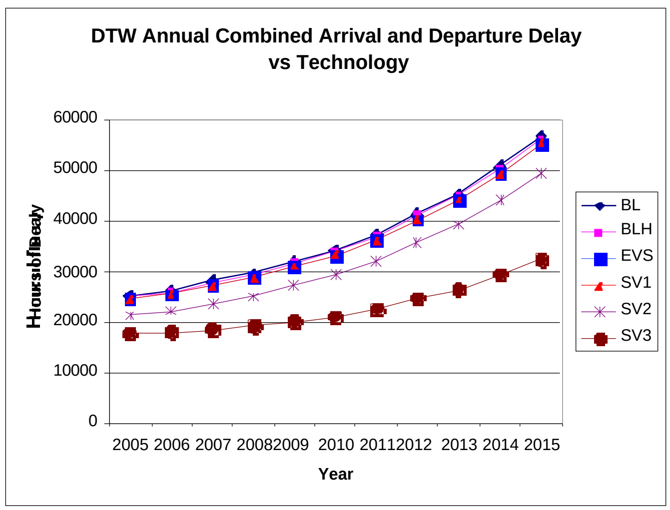


Table 3-11. DTW 10-Year Combined Arrival and Departure Savings

Technology	Minutes in millions	1997 Constant $ in millions		Present value $ in millions		Then-year $ in millions	
		Lower bound	**Upper bound**	**Lower bound**	**Upper bound**	**Lower bound**	**Upper bound**
BLH	2.5	71	116	32	53	96	158
EVS	3.1	86	141	39	64	117	193
SV1	0.9	24	39	11	17	33	54
SV2	5.9	164	270	74	122	224	368
SV3	13.6	376	619	165	271	519	855

Chicago O’Hare International (ORD)

OPERATIONAL ISSUES

Chicago O’Hare capacity is strongly affected by the ability to use three independent arrival runways (“triples” or “trips”) in VMC. In IMC, one of the parallel runway configurations (9s, 14s, 22s, 27s, or 32s) must be used. We assume SVS technologies will allow use of the 3 arrival runways in all IFR conditions.

In some of the triple configurations, heavy jets are prohibited from landing on one of the long runways. In others, only turboprops may use one of the runways. The model computes the arrival mix on the non-restricted runways that balances arrival rates for all aircraft classes. ORD also uses a mixed arrival and departure mode where arrival spacing allows two departures between each arriving pair. Special code in the ORD model computes the runway capacity in this mode.

Figure 3-12 shows the layout of ORD. Table 3-12 identifies the runway configurations used at ORD. Table 3-13 contains the ORD benefit estimates.

Figure 3–12. Chicago O’ Hare International Airport, Chicago, Illinois

Table 3-12. ORD Runway Configurations

Configuration	Runway											
	4L	4R	9L	9R	14L	14R	22L	22R	27L	27R	32L	32R
Depart Only	Not modeled, assume two runways in use											
Plan B Trip 22					AT	A	M	A	D			
Plan B Trip 27					AT	A	D	A	D	AX		
Parallel 27 Trip 32L							D		A	A	M	D
Plan X	D	A	M	A							D	D
Plan Weird Trip 27							D	A	A	AX	D	

Table 3-12. ORD Runway Configurations (Continued)

Configuration	Runway											
	4L	4R	9L	9R	14L	14R	22L	22R	27L	27R	32L	32R
Plan B						A	D	A	D			
Plan Weird							D	A	A		D	
P27s							D		A	A	D	D
Mod Plan X	D	A	A	D								D
P9s depart 4L 22L	D		A	M			D					
P9s depart 32R 22L			A	M			D					D
P9s depart 22L			A	M			D					
P9s depart 4L	D		A	M								
P9s depart 32R			A	M								D
P14s			D		A	A	D		D			
P14s no depart 27			D		A	A	D					
P14s no depart 9	D				A	A	D		D			
P14s no depart 9 or 4					A	A	D		D			
P14s no depart 22			D		A	A			D			
P14s depart 9s			D	D	A	A						
P32s									D		M	M
P22s							M	M	D	D		

A: arrival only for any type of aircraft, AT: turboprop arrivals, AX: any arrivals except heavy jets,

D: departures only, M: mixed operations - arrival and departures

RESULTS

The results for ORD are shown in Figure 3-12 and Table 3-13. The ability to use three arrival runways in IFR generates a tremendous benefit.

Figure 3–13. Combined Arrival and Departure Dalay for ORD

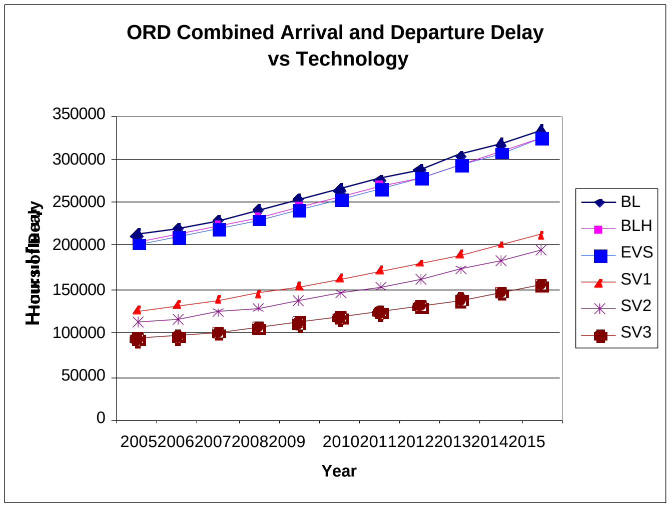


Table 3-13. 10-year Arrival and Departure Savings for Chicago

Technology	Minutes in millions	1997 Constant $ in millions		Present value $ in millions		Then-year $ in millions	
		Lower bound	**Upper bound**	**Lower bound**	**Upper bound**	**Lower bound**	**Upper bound**
BLH	4.2	117	192	54	88	158	260
EVS	5.5	154	253	71	118	207	341
SV1	62.1	1,723	2,837	792	1,304	2,337	3,848
SV2	72.2	2,004	3,300	921	1,517	2,717	4,475
SV3	89.9	2,494	4,108	1,142	1,880	3,389	5,580

Dallas-Fort Worth International (DFW)

Operational Issues

Dallas has tremendous runway capacity and wide open airspace. The runways are widely dispersed, which allows independent operation, but wide dispersion also makes runway balancing more difficult. Most of the terminals are situated on the east side of the airport, which can lead to either imbalance between east and west runways or long taxi times from the west runways. Optimized runway balancing was an important feature of P-FAST[12] at DFW.

[12] Passive Final Approach Spacing Tool, a component of the NASA/FAA Center TRACON Automation System (CTAS)

In severe crosswind conditions the main north-south runways can be closed and traffic restricted to the two diagonal runways. The diagonal runways are limited to Cat I operations. SVS technologies allow the use of the diagonals in Cat II and III conditions. SVS also allows the use of converging approaches to the diagonals and the north/south runways during IFR conditions.

At DFW, some runways permit only turboprop departures. The model adjusts the departure mix on the other runways to reflect this.

Figure 3-14 shows the layout of DFW. Tables 3-14 and 3-15 identify the runway configurations used at DFW. Table 3-16 contains the DFW benefit estimates.

Figure 3–14. Dallas-Fort Worth International Airport, Dallas/Fort Worth, Texas

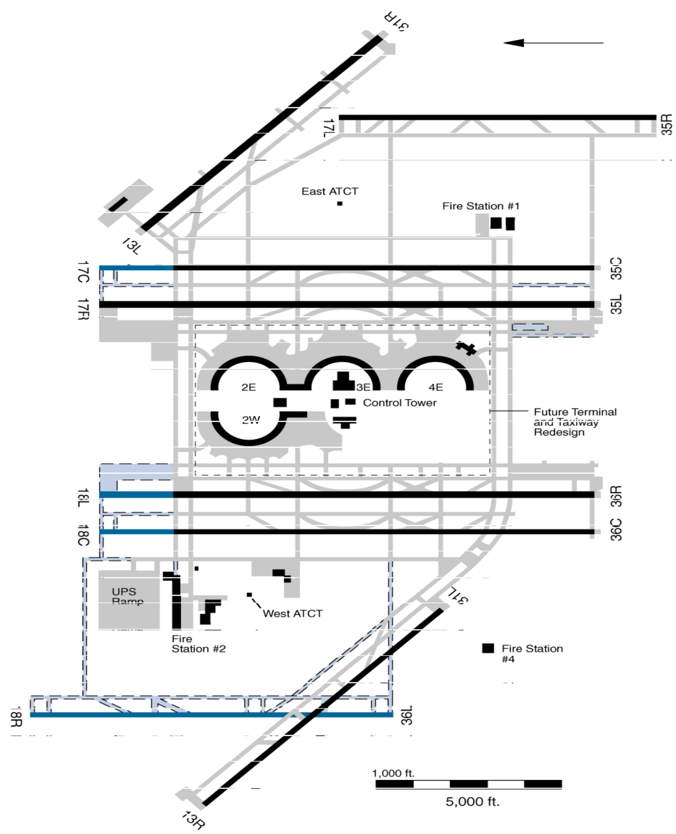


Table 3-14. Dallas-Fort Worth International Configurations (North Flow)

Configuration	Runway							
	MC	36L	36R	35L	35C	35R	31L	31R
Northflow	VFR & SVS	A	D	D	A	A	DT	A
Northflow	VFR & SVS	A	D	D	A	AD	DT	
Only 31	Cat I & SVS						AD	AD
No 31	Cat III	A	D	D	A	AD		

DT = Turboprop departures

Table 3-15. Dallas-Fort Worth International Configurations (South Flow)

Configuration	Runway							
	MC	17L	17C	17R	18L	18R	13L	13R
Southflow	VFR & SVS	A	A	D	D	A	DT	A
Southflow	VFR & SVS	A	A	D	D	A	DT	
Only 13	Cat I & SVS						AD	AD
No 13	Cat III	AD	A	D	D	A		

RESULTS

Figure 3-15 and Table 3-16 display the savings for DFW. DFW is one of the four airports where we restricted the TAF projected demand. In this case, we cut off the demand growth at the 2011 level. Dallas shows significant benefits, particularly in the later years.

Figure 3–15. DFW Annual Combined Arrival and Departure Delay

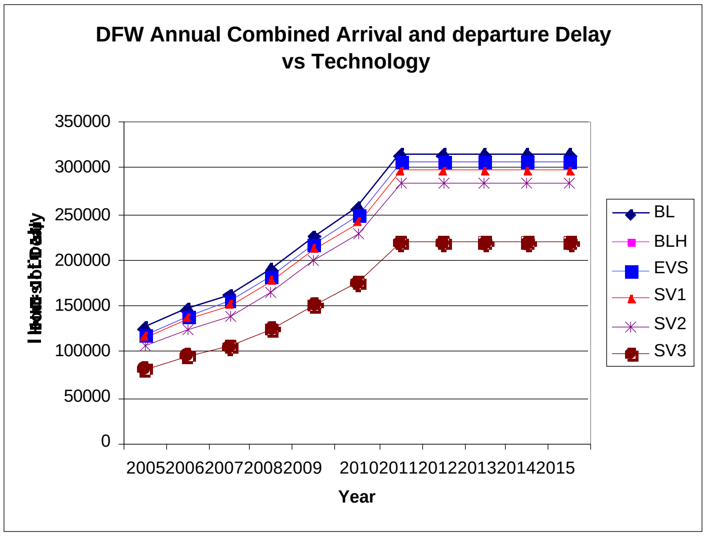


Table 3-16. 10-Year Combined Arrival and Departure Savings for Dallas-Ft. Worth

Technology	Minutes in millions	1997 constant $ in millions		Present value $ in millions		Then-year $ in millions	
		Lower bound	Upper bound	Lower bound	Upper bound	Lower bound	Upper bound
BLH	3.8	106	175	49	81	144	236
EVS	3.8	107	175	49	81	144	237
SV1	8.2	228	376	103	170	312	513
SV2	16.4	456	751	208	343	620	1,021
SV3	47.6	1,322	2,176	594	978	1,806	2,974

Los Angeles International (LAX)

Operational Issues

Los Angeles can operate its two pairs of parallel runways independently in IMC conditions. The airspace is crowded in the Los Angeles area, and the lineup for LAX starts many miles to the east. Aircraft are fed into the line from the north and south (and even from directly below for flights from Ontario Airport).

Airport capacity suffers when east flow approaches are required. Part of the reason is increased ROTs for the runways in east flow and part is because the fact that east flow is infrequent and the patterns less practiced.

Unlike the other nine airports, LAX experiences a high proportion of dry IMC-1 conditions during which the airport operates with 2.5 nautical mile minimum separations. Under wet IMC-1 conditions, the airport reverts to 3.0 nautical mile minimum separations.

Two sets of IMC-1 input files are required for LAX to cover the dry and wet conditions. A second set of ROTs also is added for the east flow runways.

Figure 3-17 and Table 3-18 show the results for LAX. Los Angeles is one of the four airports where we limited the demand was held at the 2004 level.

Figure 3-16 shows the layout of LAX. Table 3-17 identifies the runway configurations used at LAX. Figure 3-17 and Table 3-18 contains the LAX benefit estimates.

Figure 3–16. Los Angeles International Airport, Los Angeles, California

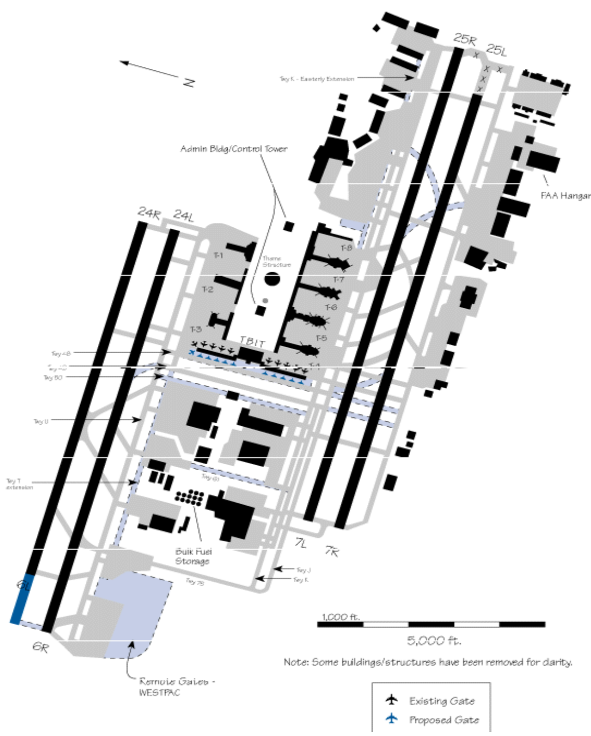


Table 3-17. Los Angeles International Configurations

Configuration	MC	Runway							
		6L	6R	7L	7R	25L	25R	24L	24R
West Flow	VFR – Cat I					AD	AD	AD	AD
West Flow	Cat II & III					A	D	D	A
East Flow	VFR – Cat I	AD	AD	AD	AD				
East Flow	Cat II & III	A	D	D	A				

RESULTS

Results for LAX are similar to those for Atlanta. SVS technologies allow reduced arrival and departure minimums which allow operations under conditions where the airport otherwise would be closed.

Los Angeles, like Atlanta, is congested and fundamentally limited by the number of its runways. The combined arrival and departure reduced minimums with SV2 provide significant benefits, but, by far, the greatest reduction comes from reduced separations.

Figure 3–17. Combined Arrival and Departure Savings for Los Angeles

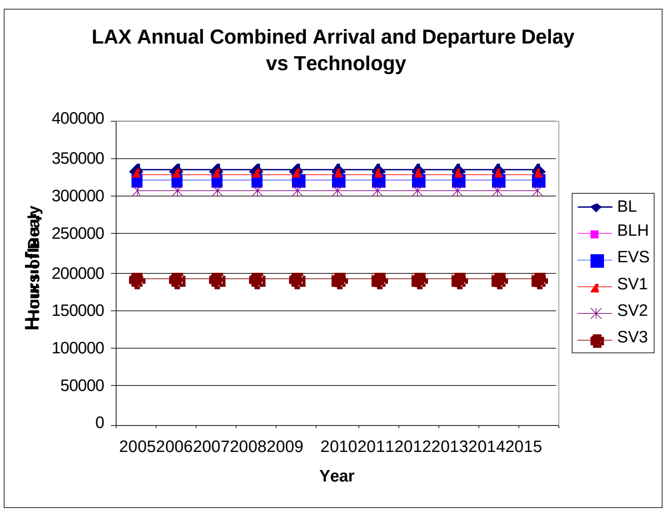


Table 3-18. 10-Year Combined Arrival and Departure Savings for Los Angeles

Technology	Minutes in millions	1997 constant $ in millions		Present value $ in millions		Then-year $ in millions	
		Lower bound	**Upper bound**	**Lower bound**	**Upper bound**	**Lower bound**	**Upper bound**
BLH	7.0	193	318	90	149	260	429
EVS	7.0	193	318	90	149	260	429
SV1	2.0	55	91	26	43	74	123
SV2	16.0	444	732	208	342	599	986
SV3	85.8	2,382	3,922	1,115	1,836	3,208	5,283

Minneapolis-St. Paul (MSP)

Operational Issues

The parallel 30/12 runways, formerly known as 29/11 at Minneapolis-St Paul International Airport are spaced 3,380 feet apart. The Precision Runway Monitor (PRM) is installed and operating at MSP

Planning by the FAA for the new 17/35 runway operations is fairly advanced, and the anticipated configurations are well defined. One exception is the minima that will be approved for conducting converging approaches to Runway 35 and the Parallel 12s or 30s. We used minimums for similar configurations at ORD in the MSP model.

Although the 50-second average arrival ROT is not documented for MSP, (and hence the ability to use 2.5 nautical mile spacing is not currently authorized), it is anticipated that this authorization will be obtained shortly after the new runway opens. The existing exits and traffic mix should easily meet the requirement. It has not been a concern, until now, as current operations space arrivals to accommodate an intervening departure, and thus the ability to space arrivals at 2.5 nautical miles would not provide any operational advantage. Where such spacing may provide an advantage, we use it in the analysis.

As with Chicago, Newark, and Dallas, we assume SVS technology will allow use of converging approaches in IFR conditions. At Minneapolis this means the “12s Arrival Rush” and “30s Arrival Rush” triple-arrival runway configurations are available in IFR.

Minneapolis can also take advantage of AILS technology on the closely spaced 12s and 30s. We assume AILS will be available with SV3.

Figure 3-18 is a diagram of the Minneapolis airport including the runway under construction. Table 3-19 lists the Minneapolis-St. Paul runway configurations.

Figure 3–18. Minneapolis-St Paul International Airport

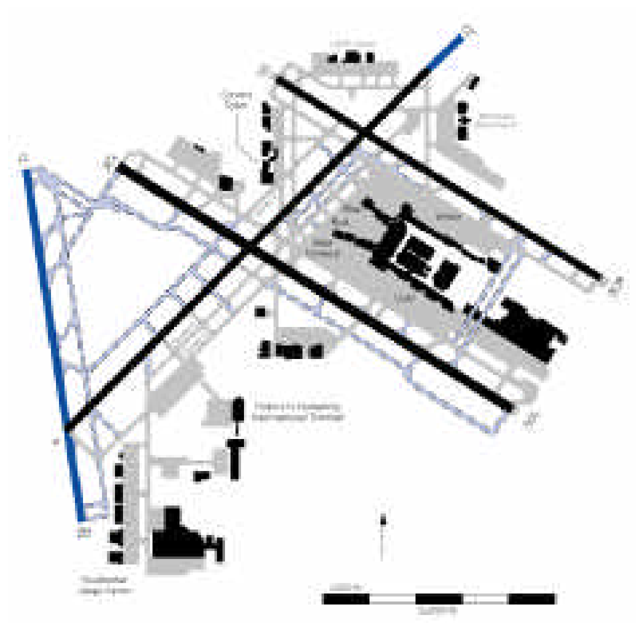


Table 3-19 contains the runway configurations used at MSP.

Table 3-19. Minneapolis-St. Paul Configurations

Configuration	MC	Runway							
		30R	30L	12R	12L	4	22	17	35
Departure only	IFR	D	D	D	D	D	D	D	D
30s arrival rush—SVS IFR	VFR	A/D	A/D						A
30s departure rush	VFR	A/D	A/D					D	
30s departure rush	IFR	dependent A/D						D	
30s departure rush—AILS	IFR	A/D	A/D					D	
12s arrival rush—SVS IFR	VFR			A/D	A/D				A
12 departure rush	VFR			A/D	A/D			D	
12 departure rush	IFR			dependent A/D				D	
12 departure rush—AILS	IFR			A/D	A/D			D	
30s low visibility	IFR	D	A/D						
12s low visibility	IFR			A/D	D				
17-35 west crosswind	VFR	A/D	A/D						
17-35 west crosswind	IFR	dependent A/D							
17-35 west crosswind—ILS	IFR	A/D	A/D						
17-35 east crosswind	VFR			A/D	A/D				
17-35 east crosswind	IFR			dependent A/D					
17-35 east crosswind—AILS	IFR			A/D	A/D				
12-30 SW crosswind	all						A	A/D	
12-30 NE crosswind	all					D			A/D
4 only	all					A/D			

22 only	all						A/D		
17 only	all							A/D	
35 only	all								A/D

RESULTS

The savings for Minneapolis are displayed in Figure 3-19 and Table 3-20. Minneapolis results indicate respectable savings. At Minneapolis, the savings resulting from reductions in arrival delays dominate over departure improvements. Reduced minimums, additional configurations, reduced arrival separations all show significant benefits. Simple reduction of the departure minimum with BLH has a small effect.

Figure 3–19. Combined Arrival and Departure Delays for Minneapolis

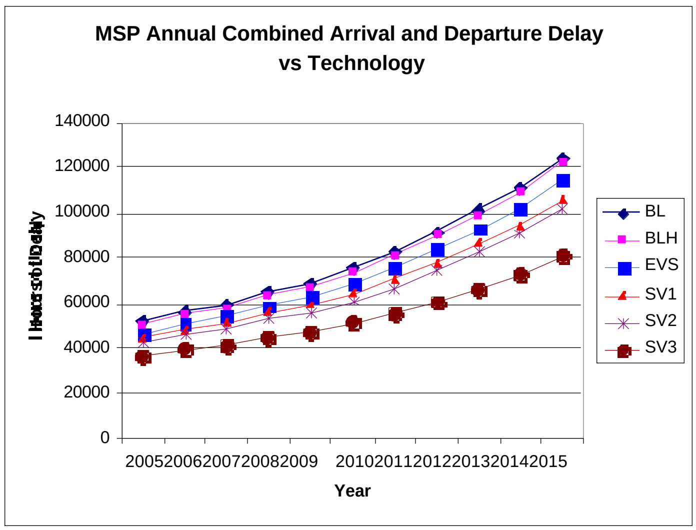


Table 3-20. 10-Year Combined Arrival and Departure Savings for Minneapolis

Technology	Minutes in millions	1997 constant $ in millions		Present value $ in millions		Then-year $ in millions	
		Lower bound	Upper bound	Lower bound	Upper bound	Lower bound	Upper bound
BLH	0.74	21	34	9	16	28	46
EVS	4.2	116	191	53	87	158	260
SV1	7.1	197	325	87	144	271	446
SV2	9.2	256	422	114	188	351	579
SV3	16.5	457	752	201	332	629	1,036

Seattle-Tacoma (SEA)

Operational Issues

Our model of SEA includes some unavoidable uncertainty. Completion of the new runway (16W/34W) is still 7 years in the future, and operational procedures are not yet in place. We discussed potential procedures and complicating factors with Seattle FAA personnel. The potential procedures included in our models represent expert opinion on what may work, but are *not* to be interpreted as a commitment to implement, or even evaluate these procedures. Much more planning, testing, and analysis will be required before formal procedures are developed.

VMC operations will have considerable of flexibility with the new third runway. Ground operations will become more complicated (and likely affect capacity) as the planned taxiway system requires arrivals to and departures from the new runway to cross both of the current runways.

In IMC, arrivals will be staggered to the inboard and outboard runways, with departures between each arriving pair (taxiing traffic permitting). The middle runway is not used, because its departures would require problematic coordination with arrivals and departures on the other two runways. We also explored a strategy with departures from the center runway only. These departures need to be coordinated with arrivals to the other two runways to ensure that there is not an arrival within 2 miles of threshold. It proved to be an inferior strategy.

In IMC south flow, interaction with traffic to Boeing Field (BFI), located north of SEA, becomes an issue. Currently, traffic to SEA is turned onto a course maintaining 1,000 feet vertical separation from BFI traffic, until it has crossed the BFI arrival path. The new runway will require the same separation technique, but BFI traffic will be at a higher altitude (farther from the BFI runway). This will make it more difficult for controllers to ensure separation, and there is a possibility that TCAS alerts will begin to wreak havoc with attempts to run approaches to SEA 16W and BFI 13 independently.

Today, departures are made on the inboard runway (16L/34R) and arrivals on 16R/34L. In the future, in VMC, the new runway (16W/34W) will also be used for arrivals. 16R/34L and 16W/34W are well designed arrival runways with high-speed exits. Runway 16L/34R is a well-designed, 11,900-foot departure runway. Because 16R/34L and 16W/34W are only 1,700 feet apart, in IMC the arrival runways will switch to 16L/34R and 16W/34W, which are 2,500 feet apart. The switching of 16L/34R from departures to arrival and 16R/34L from arrivals to departures is likely to generate some operational problems. If SVS with AILS could support 1,700-foot runway separations, the operations might be simplified.

The runway configurations are not changed for SVS technologies. As with Minneapolis, Detroit, and New York Kennedy, the SV3 technology includes AILS capability.

Figure 3-20 shows the layout of the Seattle-Tacoma Airport.

Figure 3–20. Seattle-Tacoma Airport

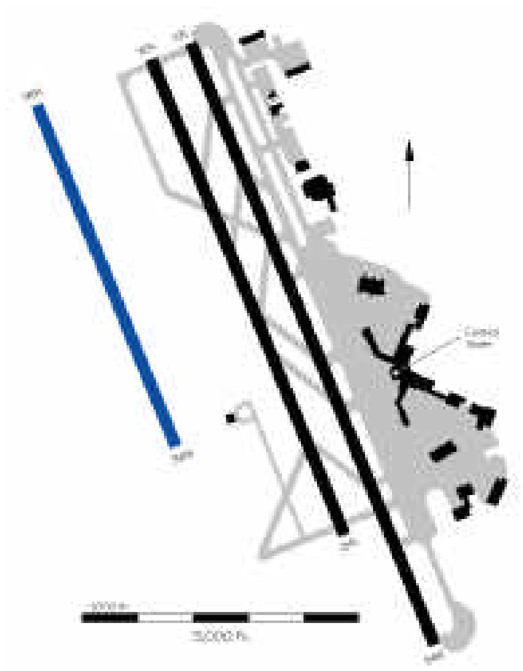


Table 3-21 displays the runway configurations modeled for SEA.

Table 3-21. Seattle-Tacoma Configurations

Configuration	MC	Runway					
		16W	16R	16L	34W	34L	34R
Normal south	VFR	A	A or D	D			
Normal south w/o AILS	IFR	A/D Dep.		A/D Dep.			
Normal south with AILS	IFR	A/D Ind.		A/D Ind.			
Normal north	VFR				A	A or D	D
Normal north w/o AILS	IFR				A/D Dep.		A/D Dep.
Normal north with AILS	IFR				A/D Ind.		A/D Ind.

Benefits at Seattle are balanced between arrivals and departures. The benefits from reduced arrival minimums are diminished at Seattle because the airport already has a 300-foot minimum Cat III runway. Savings from reduced departure minimums are significant and are supported by Alaska Airlines' experience with the Flight Dynamics, Inc. Head-Up Guidance System™.

Figure 3–21. SEA Annual Combined Arrival and Departure Delay

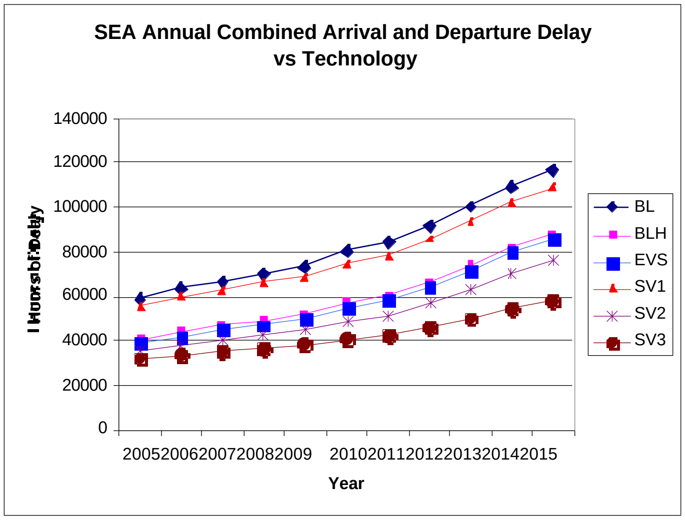


Table 3-22. 10-Year Combined Arrival and Departure Savings for Seattle-Tacoma

Technology	Minutes in millions	1997 constant $ in millions		Present value $ in millions		Then-year $ in millions	
		Lower bound	**Upper bound**	**Lower bound**	**Upper bound**	**Lower bound**	**Upper bound**
BLH	14.0	389	640	$177	292	529	871
EVS	15.4	427	703	$195	321	580	955
SV1	3.2	89	147	$40	65	123	202
SV2	19.4	538	886	$244	402	734	1,208
SV3	25.2	699	1,151	$313	515	958	1,577

References

[1] Terminal Area Productivity Program Runway Occupancy Time Analysis, W. Weiss and T. Thrasher, CSSI Inc, January 15, 1997.

[2] Benefit Estimates of Terminal Area Productivity Program Technologies, Hemm, et al. NASA CR-1999-208989, January 1999.

[3] A-1 Benefit Estimates of Terminal Area Productivity Program Technologies, Hemm, et al. NASA CR-1999-208989, January 1999.

Appendix A
Arrival Separations

Reducing interarrival separations directly increases capacity and reduces delays. At highly congested airports such as Atlanta and Los Angeles, where runway options are limited, separation reduction is the only way, other than building new runways, to make significant improvements in capacity. Synthetic vision technologies potentially can allow safe reductions in interarrival separations.

The ability to reduce separations is fundamentally based on the assumption that current actual separations are larger than necessary for safety. As discussed in Reference A-1, our capacity models begin with the minimum separations required by the FAA and, based on uncertainties in speed, position, wind, and delivery, estimate the spacing the controller will establish at the head of the common path to ensure the minimum separations are not violated. The common path is defined as the distance from the threshold where the controller can make the last speed or direction correction. In radar-controlled conditions, the minimum separations are established by the controller based on the most limiting of runway occupancy, radar, and communications response time, or wake vortex constraints. In visual approach conditions, separations are established by the aircrew based on runway occupancy, aircraft and crew response time, and wake vortex constraints. We assume the aircrew faces the same uncertainties as the controller.

To gain a better understanding of the potential for separation reduction, we modified the single-arrival runway spreadsheet model developed under a previous task. The spreadsheet model incorporates all the variables for an arrival runway found in the capacity models, but uses closed-form versions of the arrival algorithms that facilitate display of additional variables and intermediate results. For this task, we added displays of threshold interarrival distances to improve our understanding of the potential for reduced separations.

Figure A-1 shows the input and output portion of the spreadsheet model. The case shown includes the inputs used for Dallas-Ft.Worth in IFR1 conditions. The input variables are repeated in Table A-1.

Figure A–1. Spreadsheet Model Input and Output

Single Runway All-Arrival Model

Based on the explicit relationships in the NASA/CR-1999-208989, pages A-7 and A-10

This model includes the exponential inefficiency buffer distribution
(modified May 2000 to correct mu_{ROT} and add distance matrix)

INPUTS

Common Path (nmi.)	**D**	7.0
SD Speed (knots	**SDV**	5.00
SD Position (nmi.)	**SDX**	0.250
SD Wind (knots)	**SDW**	7.5

Aircraft Data

Class	Speeds	Mix	ROT	SDROT
small	135	0.14	42	8
large	140	0.71	47	8
B-757	140	0.075	47	8
heavy	145	0.075	53	8

	seconds	nmi.	feet
Mean of delivery inefficiency buffer (1/lambda)	6.44	0.25	1,520

RESULTS

Expected A-A Capacity	**31.5**	**per hour**
Perfect A-A Capacity	**46.7**	**per hour**

Target Separation Matrix (input matrix)

	Leader			
Follower	**small**	**large**	**757**	**heavy**
small	2.5	4	5	6
large	2.5	2.5	4	5
757	2.5	2.5	4	5
heavy	2.5	2.5	4	4

Capacity: 31.5 per hour

Spacing at the Threshold in nautical miles
(spacing includes the delivery inefficiency buffer)

	Leader			
Follower	**small**	**large**	**757**	**heavy**
small	4.1	5.3	6.4	7.7
large	4.1	4.0	5.6	6.3
757	4.1	4.0	5.6	6.3
heavy	4.1	4.0	5.6	5.5

Spacing at the Head of the Common Path in nautical miles
(spacing includes the delivery inefficiency buffer)

	Leader			
Follower	**small**	**large**	**757**	**heavy**
small	4.1	5.0	6.1	7.2
large	4.3	4.0	5.6	6.1
757	4.3	4.0	5.6	6.1
heavy	4.6	4.3	5.9	5.5

MIT / ROT Constaint Matrix (output matrix)

	Leader			
Follower	**small**	**large**	**757**	**heavy**
small	MIT	MIT	MIT	MIT
large	MIT	MIT	MIT	MIT
757	MIT	MIT	MIT	MIT
heavy	MIT	MIT	MIT	MIT

Table A-1. Input Variables

Input variables	Sample values	
Common path length (statute miles)	7	
Standard deviation of aircraft speed (knots)	5	
Standard deviation of aircraft position (nautical miles)	0.25	
Standard deviation of wind difference between aircraft (knots)	7.5	
Aircraft mix (fraction):		
Small	0.14	
Large	0.71	
Boeing 757	0.075	
Heavy	0.075	
Runway occupancy time / standard deviation (seconds):	Dry	Wet
Small	42 / 8	50 / 8
Large	47 / 8	56 / 8
Boeing 757	47 / 8	56 / 8
Heavy	53 / 8	64 / 8
Aircraft speed (knots):		
Small	135	
Large	140	
Boeing 757	140	
Heavy	145	

Table A-1. Input Variables

Input variables	Sample values
Delivery inefficiency buffer (nautical miles)	0.25

Tables A-2 and A-3 show the FAA minimum separations for radar-controlled visual and instrument landing conditions. The 2.5 versus 3.0 nautical mile separations are allowed under limited conditions. Table A-4 contains a set of separations that are recommended in FAA-76-8A for use in the FAA capacity model for visual operating conditions.[13]

Table A-2. FAA 2.5 Separation Matrix

	Leader			
Follower	Small	Large	B-757	Heavy
Small	2.5	4.0	5	6
Large	2.5	2.5	4	5
B-757	2.5	2.5	4	5
Heavy	2.5	2.5	4	4

Table A-3. FAA 3.0 Separation Matrix

	Leader			
Follower	Small	Large	B-757	Heavy
Small	3	4	5	6
Large	3	3	4	5
B-757	3	3	4	5
Heavy	3	3	4	4

Table A-4. Visual Separation Matrix

	Leader			
Follower	Small	Large	B-757	Heavy
Small	1.9	2.7	3.5	4.5
Large	1.9	3.0	3.0	3.6
B-757	1.9	1.9	3.0	3.6
Heavy	1.9	1.9	2.7	2.7

[13] FAA-78-8A predates the requirement for special B-757 separation. We estimated the B-757 separations by scaling from the FAA 3.0 matrix.

Tables A-5 through A-7 show the hourly capacities and threshold interarrival separations that correspond to the separations matrices of Tables A-2 through A-4 with the input variables given in Table A-1.

Table A-5. Results for FAA 2.5 Separation Matrix

Capacity: 31.5 per hour

Spacing at the Threshold in nautical miles
(spacing includes the delivery inefficiency buffer)

	Leader			
Follower	**small**	**large**	**757**	**heavy**
small	4.1	5.3	6.4	7.7
large	4.1	4.0	5.6	6.3
757	4.1	4.0	5.6	6.3
heavy	4.1	4.0	5.6	5.5

Table A-6. Results for FAA 3.0 Separation Matrix

Capacity: 29.0 per hour

Spacing at the Threshold in nautical miles
(spacing includes the delivery inefficiency buffer)

	Leader			
Follower	**small**	**large**	**757**	**heavy**
small	4.6	5.3	6.4	7.7
large	4.6	4.5	5.6	6.3
757	4.6	4.5	5.6	6.3
heavy	4.6	4.6	5.6	5.5

Table A-7. Results for Visual Separation Matrix

Capacity: 35.5 per hour

Spacing at the Threshold in nautical miles
(spacing includes the delivery inefficiency buffer)

	Leader			
Follower	**small**	**large**	**757**	**heavy**
small	3.6	3.9	4.7	6.1
large	3.7	3.8	4.5	4.8
757	3.7	3.8	4.5	4.8
heavy	3.8	3.9	4.2	4.2

SVS can be used to reduce separations in at least two ways. The first is by allowing aircraft equipped with SVS to conduct “visual approaches” in radar conditions. In such a case, we should expect separations similar to those achieved with the FAA-76-8A inputs. This method was used in the current study with the input separation matrix shown in Table A-8 and resulting in the capacity and threshold separations (at DFW) shown in Table A-9.

Table A-8. SVS Separation Matrix

Follower	Leader			
	Small	Large	B-757	Heavy
Small	2.3	2.7	3.5	4.5
Large	2.3	3	3	3.5
B-757	2.3	2.3	3	3.5
Heavy	2.3	2.3	3	3

Table A-9. Results for SVS Separation Matrix

Capacity: 35.0 per hour
Spacing at the Threshold in nautical miles
(spacing includes the delivery inefficiency buffer)

	Leader			
Follower	**small**	**large**	**757**	**heavy**
small	3.8	4.2	4.7	6.1
large	3.9	3.8	4.5	4.7
757	3.9	3.8	4.5	4.7
heavy	3.9	3.9	4.6	4.5

There are a few problems with the visual approach concept. One is the basic assumption that aircrews, given accurate traffic information and synthetic vision displays, will fly closer. It may be that much of the closer spacing in visual conditions today is caused by the inability of aircrews to judge distances, especially for the extended wake vortex distances, and that, when they have accurate data, they will actually increase their spacing from current levels. The other major problem is that visual approaches in radar conditions require a transfer of separation responsibility from the controller to the aircrew, which neither may be willing to make.

Fortunately, there is a second way in which synthetic vision can reduce separations. The traffic information and presentation available with SVS (with ADS-B) will allow the aircrew to accurately follow the preceding aircraft at a specified distance. For example, the controller could request that the aircrew follow the preceding traffic at 3.25 nautical miles or to fly to a 3.25 nautical mile separation at the threshold. The aircrew could comply up to the point where final landing speed must be established. This capability would effectively reduce the position uncertainty, wind uncertainty, speed uncertainty, and the common path length. Input parameters corresponding to these potential improvements are shown in Table A-10. Tables A-11 through A-13 show the resulting capacities and threshold separations.

Table A-10. Reduced Common Path and Uncertainty Input Variables

<table>
<tr><th>Input Variables</th><th colspan="2">Reduced CommonPath</th><th>Reduced Uncertain-ties</th><th>Both</th></tr>
<tr><td>Common path length (statute miles)</td><td colspan="2">5</td><td>7</td><td>5</td></tr>
<tr><td>Standard deviation of aircraft speed (knots)</td><td colspan="2">5</td><td>3</td><td>3</td></tr>
<tr><td>Standard deviation of aircraft position (nautical miles)</td><td colspan="2">0.25</td><td>0.08</td><td>0.08</td></tr>
<tr><td>Standard deviation of wind difference between aircraft (knots)</td><td colspan="2">7.5</td><td>5</td><td>5</td></tr>
<tr><td>Aircraft mix (fraction):</td><td colspan="2"></td><td colspan="2" rowspan="17">All other variables unchanged</td></tr>
<tr><td>Small</td><td colspan="2">0.14</td></tr>
<tr><td>Large</td><td colspan="2">0.71</td></tr>
<tr><td>Boeing 757</td><td colspan="2">0.075</td></tr>
<tr><td>Heavy</td><td colspan="2">0.075</td></tr>
<tr><td>Runway occupancy time and standard deviation (seconds):</td><td>Dry</td><td>Wet</td></tr>
<tr><td>Small</td><td>42 / 8</td><td>50 / 8</td></tr>
<tr><td>Large</td><td>47 / 8</td><td>56 / 8</td></tr>
<tr><td>Boeing 757</td><td>47 / 8</td><td>56 / 8</td></tr>
<tr><td>Heavy</td><td>53 / 8</td><td>64 / 8</td></tr>
<tr><td>Aircraft speed (knots):</td><td colspan="2"></td></tr>
<tr><td>Small</td><td colspan="2">135</td></tr>
<tr><td>Large</td><td colspan="2">140</td></tr>
<tr><td>Boeing 757</td><td colspan="2">140</td></tr>
<tr><td>Heavy</td><td colspan="2">145</td></tr>
<tr><td>Delivery inefficiency buffer (nautical miles)</td><td colspan="2">0.25</td></tr>
</table>

Table A-11. Results for FAA 2.5 Matrix with Reduced Common Path

Capacity: 33.1 per hour
Spacing at the Threshold in nautical miles
(spacing includes the delivery inefficiency buffer)

	Leader			
Follower	**small**	**large**	**757**	**heavy**
small	3.8	5.2	6.3	7.5
large	3.8	3.8	5.3	6.3
757	3.8	3.8	5.3	6.3
heavy	3.8	3.8	5.4	5.3

Table A-12. Results for FAA 2.5 Matrix with Reduced Uncertainties

Capacity: 35.6 per hour
Spacing at the Threshold in nautical miles
(spacing includes the delivery inefficiency buffer)

	Leader			
Follower	**small**	**large**	**757**	**heavy**
small	3.5	4.9	5.9	7.2
large	3.5	3.5	5.0	5.9
757	3.5	3.5	5.0	5.9
heavy	3.5	3.5	5.0	5.0

Table A-13. Results for FAA 2.5 Matrix with Both Reduced Common Path and Reduced Uncertainties

Capacity: 37.2 per hour
Spacing at the Threshold in nautical miles
(spacing includes the delivery inefficiency buffer)

	Leader			
Follower	**small**	**large**	**757**	**heavy**
small	3.3	4.8	5.9	7.1
large	3.3	3.3	4.9	5.8
757	3.3	3.3	4.9	5.8
heavy	3.4	3.3	4.9	4.8

We see from these tables that threshold separations are always above FAA minimums and that all the capacities meet or exceed that of the visual approach.

The results above indicate that it would be very useful for the SVS test program to investigate and demonstrate separation control procedures for aircrews and controllers, and identify the equipment and training necessary to fly controlled separation approaches.

Appendix B
Abbreviations

ADS-B	Automatic Dependent Surveillance – Broadcast
AILS	Airborne Information for Lateral Spacing
AMASS	Airport Movement Safety System
ASAC	Aviation System Analysis Capability
ASDE-3	Advanced Surveillance Detection Equipment—3 (ground surveillance radar)
BLH	Analysis technology: Baseline + HUD
Cat I,II,III	IFR categories defined by visibility and ceiling
CDTI	Cockpit Display of Traffic Information
CONOPS	Concept of Operations
EGPWS	Enhanced Ground Proximity Warning System
EVS	Analysis technology: Enhanced Vision System
FAA	Federal Aviation Administration
FLIR	Forward Looking Infrared
FMS	Flight management System
GPS	Global Positioning Satellite
HUD	Head-up Display
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
LAAS	Local Area Augmentation System (high accuracy satellite guidance system)
LaRC	(NASA) Langley Research Center
LNAV	Lateral Navigation
MIT	Miles-in-Trail
OAG	Official Airline Guide

PRM	Precision Runway Monitor
RIPS	Runway Incursion Prevention System
ROT	Runway Occupancy Time
ROTO	Roll-out and Turn-off
RS	Reduced Separations
RVR	Runway Visual Range
SMGCS	Surface Movement Guidance Control System
SV1 to 3	Analysis technologies: Synthetic Vision
SVS	Synthetic Vision System
TAF	(FAA) Terminal Area Forecast
TAP	(NASA) Terminal Area Productivity (Program)
TCAS	Traffic alert and Collision Avoidance System
T-NASA	Taxi Navigation and Situation Awareness
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions
VNAV	Vertical Navigation
VSAD	Vertical Situation Awareness Display

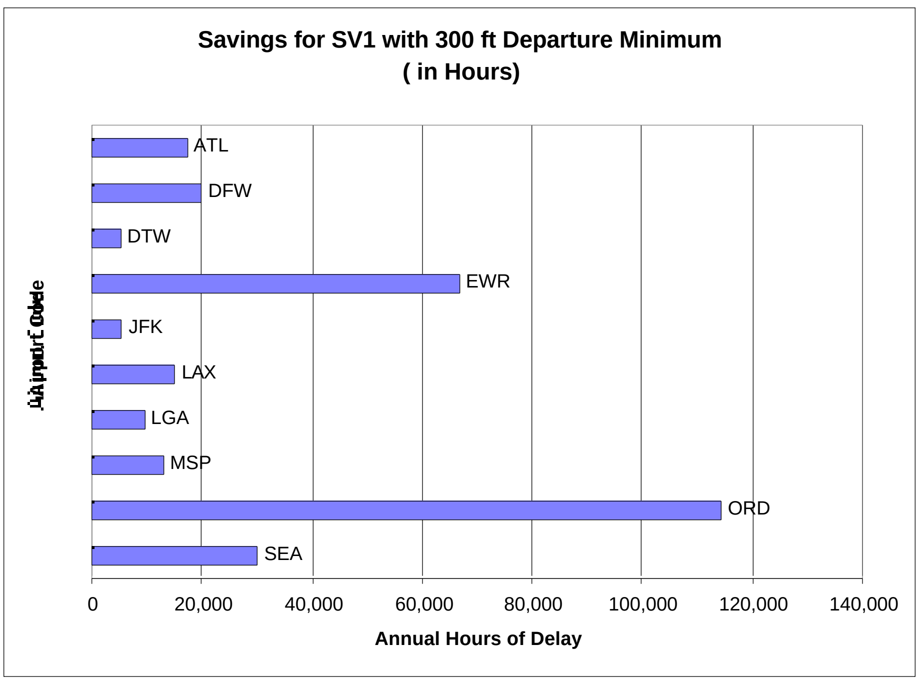
Report Addendum: LMINET Analysis

This addendum describes synthetic vision (SV) technology calculations made with the LMINET 64-airport network model. The purpose of the analysis was to investigate network effects resulting from the deployment of SV technology.

The scenario represents implementation of BLH plus SV1 technologies at the 10 airports modeled in the main task.[14] Specifically, the LMINET airport models for the 10 airports were modified to use VFR configurations in IFR conditions and to allow 300-foot visibility departures. SV1 enables the former, and BLH enables the latter.

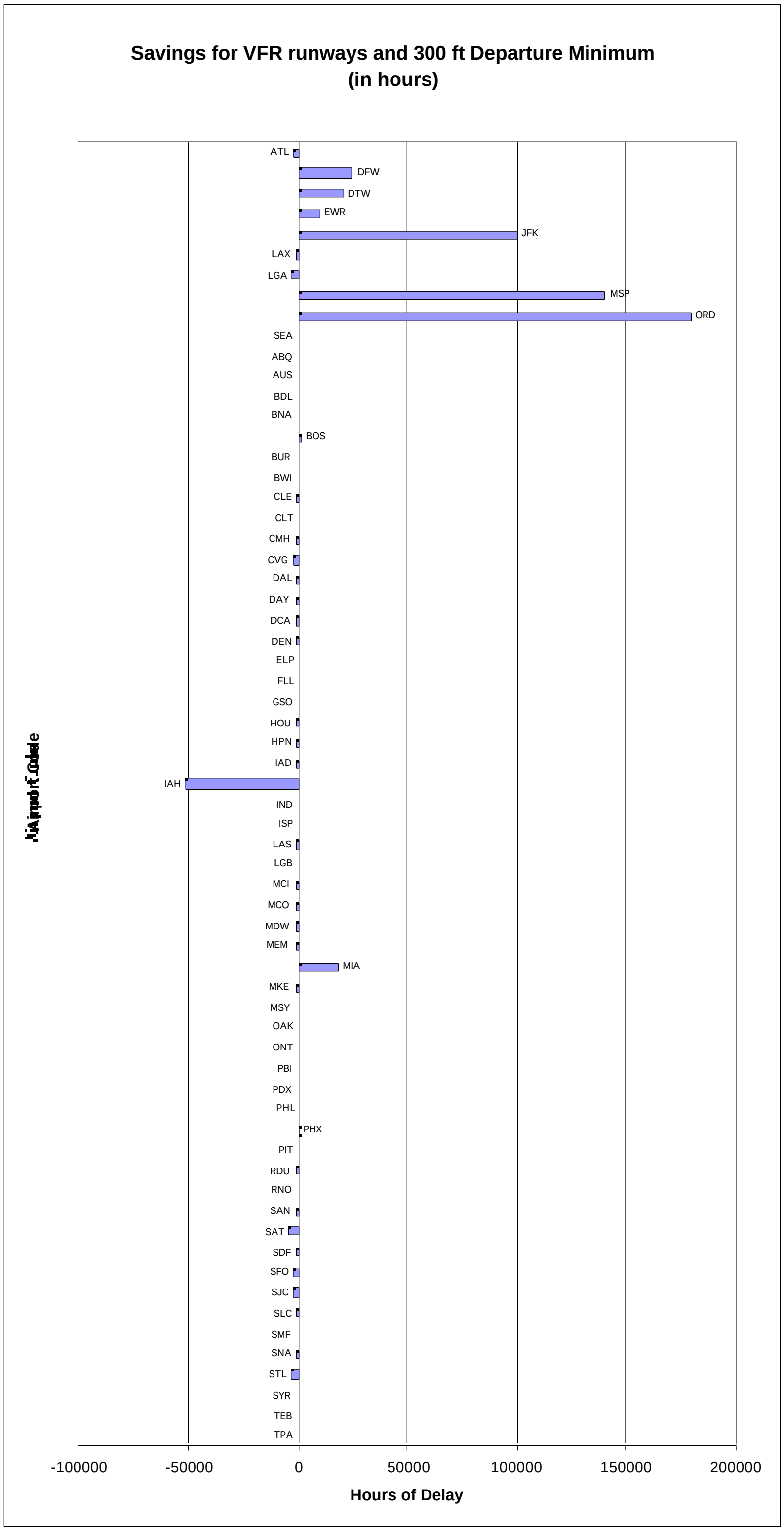
Figure 1 shows the results from the individual airport models for the 10 airports. Figure 2 on the following page shows the LMINET results for the 64 airports of that model.

Figure 1. Individual Airport Results



[14] BLH and SV1 are codes for technology capabilities described in the main report. BLH allows departures with only 300 foot visibility. SV1 allows all aircraft to operate in Category IIIb weather conditions. It also allows Category IIIb operations on all runways. Finally, SV1 allows circling and converging approaches in Category IIIb conditions.

Figure 2. LMINET Results



DISCUSSION

There are significant differences between the individual airport and LMINET results. These stem from three primary sources: runway configurations, weather assumptions, and network effects. LMINET includes a new runway at Atlanta. The individual airport models include new runways at Seattle, Detroit, and Minneapolis. The LMINET model uses the VFR configurations at New York Kennedy, while the individual model does not. These differences help explain differences in results for Atlanta, Detroit, Minneapolis, and New York Kennedy, but not for Seattle. Weather assumptions explain the differences at Seattle.

LMINET uses three days of historical national weather data (April 8, June 12, and November 29, 1996).[15] The annual delay is based on a weighted average of the delays for the three days. These data are adequate for network analysis, the primary purpose of LMINET, but may not include important airport-unique weather features. Such is the case for Seattle, where the impact of reducing departure minimums from 700 feet to 300 feet is missed because the lowest visibility for the three days is 0.9 miles.

Network effects impact all the airports and are the only cause of delay changes in airports other than the 10 that were modified. Figure 2 shows significant changes in delay at Houston (IAH) and Miami (MIA). Review of the detailed IAH and MIA results indicates that the changes are due to changes in arrival and departure demand caused by changes in capacities at feeder and destination airports. Network effects are also evident at Atlanta (ATL), New York Laguardia (LGA) and Los Angeles (LGA) where LMINET results show increased delays despite minor improvements in individual airport capacity.

CONCLUSIONS

The LMINET results generally support those from the individual airport models. Differences can be explained by model differences, input data differences (weather), and network effects.

The results of the LMINET analysis indicate that network effects are important, and may influence investment decisions. Based on the current results, one would certainly investigate ways to avoid the additional delays at IAH that result from the higher flows at its major connectors.

[15] The three days were chosen based on analysis of the 1996 weather data. June 12 had good weather across the nation. April 8 had a major bad weather event in the northeast and east coast. November 29 had bad weather across the nation.

The differences in the airport configurations used in the individual airport and LMINET models should be resolved in any future analyses.

LMINET is not designed for individual airport analysis, and the weather data used in LMINET will need revision if LMINET results are to be used for specific airport estimates.